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The influence of potato leafhopper-induced injury on crop developmental physiology and economic utility of alfalfa

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The influence of potato leafhopper-induced injury on crop developmental physiology and economic utility of alfalfa

by

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DEDICATION

This dissertation is affectionately dedicated to my children, Jamison Scott, Jacqueline Marie, and Brittany Jean. In comparison to the significance of their birth and continuing love, all other goals and accomplishments are indeed trivial.

INTRODUCTION

The objectives of insect pest management are manifold. Indeed, a concise definition of pest management remains elusive because of the multiple objectives involved and how they should be ranked. Perhaps a great deal of confusion would be alleviated if the focus were placed on the objectives of those persons making pest management decisions; namely, farmers or their agents. With this approach, there can be little doubt that the microeconomic theories of production efficiency are applicable, and the refined objective becomes one of consistently minimizing economic losses to pests. This focus is not intended to dismiss the potential advantages which frequently result from pest management, such as fewer pesticide inputs and enhanced environmental quality. It does, however, underscore the fact that agricultural enterprises are small businesses which have their own set of objectives that may or may not coincide with those of the larger community. Therefore, the current operating procedure involves microeconomic decision making by producers, constrained by the wishes of the larger community via government regulation. For example, pesticides are available for use by growers at their discretion, so long as they are used according to labelled requirements (which are regulated by public agencies). The segregation of private vs. public prerogatives is important as it directs the attention of pest management to utilizing available resources solely on the basis of economic optimization, with public concerns and policy intrinsic to the decision-making process.

With the above characterization of pest management, it becomes clear that the primary limitation for all decisions is knowledge. Indeed, in instances where pesticides are overused (or underused), the reason is because of inadequate knowledge about the biology of the host/pest relationship. For example, when pesticides are overused, it is likely because the damage function to the crop or the presence of the pest cannot be predicted with accuracy. Therefore, pesticides are used as a risk averse strategy in uncertain situations to eliminate the possibility of large economic losses. It is equally conceivable, however, that pesticides may be underused because of the same reasons. Clearly, additional knowledge about pests and their relationship to the host will provide for more efficient decisions. The economic-injury level (EIL) incorporates much of the necessary knowledge and has, by far, been the most extensively used concept in pest management for minimizing losses to pests.

Pest management systems for alfalfa, Medicago sativa L., have always been difficult to construct because the value of the forage varies from one operation to another, with no stable or recognized market. In addition, much of the necessary information on host response to insect feeding is incomplete. Traditionally, entomologists assess crop response to insect injury by measuring only the degree of insect infestation and the resultant yield loss. This approach minimizes our understanding of how plants respond to insect-induced stress by focusing on only one parameter, yield. Yield represents an end point subject to the interactions among the plant, the insect, and other stressors. In the case of alfalfa, yield also involves a quality component. A primary objective of pest management research should be, therefore, to quantify the physiological response of alfalfa to insect feeding. Particular emphasis should be placed on the yield components (i.e., stem and leaf) and quality parameters (i.e., crude protein, digestibility, intake). Indeed, detailed studies on host response represent the necessary first step for development of realistic decision indices which integrate both quality and yield loss.

The potato leafhopper (PLH), Empoasca fabae (Harris), has long been considered a serious pest of alfalfa in the North Central United States. The PLH feeds by inserting its piercing-sucking mouthparts into the phloem elements of the plant and extracting juices. Injury to the plant, then, is the result of phloem destruction and clogging by debris during the feeding process of repeatedly inserting the stylet. The disruption of plant vascular elements results in severe yellowing of plant leaves commonly referred to as "hopperburn". Symptoms begin as a discoloration or yellowing in the tips of the leaves and progress to form a complete V-shaped chlorosis over much of the leaf.

Few damage assessment studies conducted with PLH consider the concurrent physiological development of the crop. Physically, injured plants exhibit stunting, proliferation of branches, and a delay in flowering. Although each of these plant responses seem unfavorable, that conclusion may be preliminary. Van Soest (1982) points out that environmental conditions which slow the physiological ageing of a forage will, by default, increase the quality of the crop. Hence, to properly manage the effects of PLH injury on alfalfa utility (composite yield and quality), the specific rates of injury on the physiological development of the crop must be quantified.

This dissertation documents the necessary information for developing a pest management system for PLH on alfalfa. The overall objective of the study is to gather the scientific data necessary for the calculation of economic-injury levels (EILs). The goals necessary to achieve the final objective of the study were to:

1) Characterize the growth and development of the yield and yield components of alfalfa subjected to PLH feeding.
2) Determine, with the assistance of crop growth analyses, the rates of crop development for injured and uninjured plants.
3) Assess the impact of PLH-induced injury on the quality of alfalfa, with emphasis placed on the calculation and use of quality parameters predictive of animal growth.
4) Establish the effect of PLH feeding on the role of alfalfa stems and leaves to the overall utility of the crop.
5) Quantify the impact of PLH feeding on rate of development of alfalfa, and model the nutrient yield development over time.
6) Modify the conceptual and practical means of estimating the value of forages grown for on-farm applications, and use these estimates to refine the calculation of EILs.

LITERATURE REVIEW

The literature for potato leafhopper injury to alfalfa is interdisciplinary in nature, encompassing components of entomology, crop science, animal nutrition, and agricultural economics. General topics of this review fall under three broad categories: (1) potato leafhopper biology; (2) alfalfa growth and utilization; and, (3) crop and pest management of forages.

Potato Leafhopper Biology

The potato leafhopper (PLH), Empoasca fabae (Harris), has long been recognized as a pest of agricultural crops (Osborn 1896). As a serious pest, the PLH has been the focus of an enormous amount of entomological study (see Gyrisco et al. (1978) for a bibliography). Indeed, several basic and applied scientists have focused their entire career on the study of the PLH and related leafhopper species. Perhaps most notable among these was Dwight DeLong of The Ohio State University in Columbus, Ohio. Over the duration of his career, Dr. DeLong conducted hundreds of basic and systematic studies on leafhoppers, including the PLH. Therefore, much of the taxonomic and biological discussion which follows will be based on Dr. DeLong's life-long work. In addition, Dr. Micheal Ogunlana, a former graduate student at Iowa State University, summarized much of the previous work on PLH bionomics in his doctoral thesis (1973), and his work provides a foundation on which new reports can be added.

Description and distribution

The PLH has had a long standing case of mistaken identity. Indeed, this species has been recognized in the literature as having no fewer than 16 scientific names (DeLong 1931; Ogunlana 1973). Harris (1841) first described the PLH as *Tettigonia fabae* within the family Tettigoniadae. Ironically, the common name associated with this pest has been more stable through the years. First referred to as the bean leafhopper after the original work by Harris (1841), the common name potato leafhopper was later assigned (Ball 1918) and eventually approved by the Entomological Society of America (Blickenstaff 1970). The PLH is taxonomically placed in the class Insecta and order Homoptera. This species is further placed in the superfamily Cicadelloidea, family Cicadellidae, and subfamily Typhlocybinae (Borrer et al. 1976).

Heretofore, the confusion with scientific nomenclature for this species has led to a proliferation of descriptions in the literature. Most notable among these include work by Harris (1852, 1862), Gillette (1898), DeLong (1938), Fenton and Hartzell (1923), Hartzell (1923), and Osborn (1924). For this review, a general description of the PLH is provided that incorporates pertinent components from each of these pioneering investigations.

The physical appearance of PLH adults is typical of most leafhopper species. That is, the head is wider than the abdomen, which results in the body tapering posteriorly. Individuals are ca. 3 mm long and 0.7 mm wide at the base of the head. They are a pale-green color and have a characteristic row of six round white spots along the cephalic margin of the pronotum. Additionally, two parallel white stripes united with a transverse bar form a mesonotal "H" on the pronotum just posterior to the white spots. There are variations in the specific hue among individual leafhoppers, with some individuals being more yellowish than green. Wing venation of the forewings is reduced, with no cross veins except in the extreme apical portion. Nevertheless, adults are agile and fly if disturbed. Metathoracic legs are long and facilitate jumping or "hopping" as a means of short distance movement (Metcalf et al. 1967). For non-apteral movement, the adults and nymphs walk sideways along the stems or undersides of leaves.

Because of current knowledge about host preference, the above criteria will suffice to identify PLH in agronomic situations. However, to make a species determination from other members of the genus Empoasca, an examination of internal male genitalia is necessary. Anatomical features of the genitalia and the evolution of Empoasca spp. are outlined by Ross et al. (1965). DeLong (1984), in a review of taxonomically significant characters for leafhoppers, demonstrated the necessity of utilizing male genitalia for current and future species determinations.

Eggs are elongate, somewhat cylindrical, and slightly curved. Each egg is about 0.82 mm long and 0.25 mm in diameter with a translucent and pale greenish appearance. As the embryo within the egg develops, eye spots can be seen through the chorion as reddish dots on the anterior aspect of the egg. Typically, eggs are found inserted inside the stems or petioles of host plants and staining or clearing is necessary to locate and count them.

Inasmuch as PLH develop via gradual metamorphosis, individuals of each nymphal instar resemble adults except that the latter are larger, and have fully developed wings and genitalia. The first of five instars is pale white and extremely small. Succeeding instars are similar to the first, except for differences in size, eye color, and wing-pad development. The second instar is ca. 1.30 mm in length, and eye color fades from red to pinkish. The third instar is ca. 1.85 mm long, with white eyes. In addition, wing-pads begin to develop during this stage and may extend to the posterior region of the first abdominal segment. The fourth instar resembles the third, except the body length is ca. 2.10 mm and wing-pads extend through the second abdominal segment. The fifth and final instar is ca. 2.60 mm long, with off-white eyes, and wing-pads extended to the fifth abdominal segment. Although still unable to fly, the late-instars are as agile as adults and can move sideways very rapidly.

The PLH, a nearctic species, occurs throughout the eastern half of the United States and southern Canada in summer. Beyond this generalization, the geographical distribution of the PLH has been discussed by only a few workers. Early accounts by Fenton and Hartzell (1923) placed the PLH in nearly every region of the United States, as well as Canada, Mexico, Puerto Rico, and Argentina. They made no mention of a presence in Europe. DeLong (1931, 1938) refined the distribution in the United States to include the eastern, midwestern, and north-central regions. The western boundary was determined to be South Dakota, Nebraska, eastern Colorado, northeast Mexico, and east Texas. DeLong

(1938), and later work by Poos and Wheeler (1943), determined that previous records cited by Fenton and Hartzell (1923) failed to differentiate among E. fabae and two similar species, E. filamenta and E. arida.

The most comprehensive assessment of global distribution for PLH was mapped by the Commonwealth Institute of Entomology (1953). Worldwide, this species occurs only in the Western Hemisphere, covering North America (as described previously), Central America, the West Indies, and parts of South America. It seems, then, that the PLH is restricted to areas of high relative humidity (greater than 630 mm of precipitation per year and a 0.4 precipitation to evaporation ratio) and elevations at or below 1400 meters (Ross et al. 1965). Iowa satisfies all of the requisites for PLH growth and development during the summer months.

Within its global range, the PLH is polyphagous. To date, Poos and Wheeler (1949) have assembled the most comprehensive list of hosts, which includes 235 plant species. Originally, the potato (Solanum tuberosum L.) was considered to be the preferred host (Dudley and Wilson 1921; Poos and Smith (1931), Batten and Poos (1938). However, rearing studies by Poos and Wheeler (1943) demonstrated that broadbean, Vicia faba L., was preferred for both feeding and oviposition. Their tests determined that 26 generations of PLH could be reared on broadbean in the same time that 20 generations could be reared on potato. Moreover, they noted that adults reared on broadbean were larger and more vigorous than those reared on potato. Further work (Kieckhefer and Medler 1964) determined that E. fabae preferred broad bean for oviposition, followed by alfalfa

(*Medicago sativa* L.), soybean (*Glycine max* [L.]), and pea (*Pisum sativum* L.) in descending order of preference. Moreover, they determined that young succulent alfalfa tissue was preferred over older lignified tissue.

One of the most significant plant characteristics mitigating against PLH development is the presence of glandular hairs. Shade et al. (1979) demonstrated resistance to feeding and oviposition of PLH on alfalfa cultivars possessing dense glandular hairs. Presumably, the hairs limit the insects accessibility to the plant by the stylet and ovipositor.

Life and seasonal cycles

Although some of the early taxonomic confusion clouded a clear understanding of the true *E. fabae*, the life and seasonal cycles of PLH in the United States has been the topic of much research. Reports by Fenton and Hartzell (1923) and DeLong (1938, 1965, and 1971) provide some of the most accurate accounts concerning PLH development. The following characterization of PLH life history is, therefore, based primarily on these works.

The mode of reproduction is bisexual. Mating typically occurs within two days of adult emergence and adults may remain in copula for up to 45 minutes. One mating is sufficient to fertilize all the eggs a female is capable of producing over her life time. In fact, there is no difference in the number or viability of eggs laid by females mated once or multiple times. Moreover, males of a previous generation can inseminate their offspring, should the generations overlap. The preoviposition period, which includes mating and ova development, ranges from 3 to 8 days if mating occurs within a few hours after emergence.

As with preoviposition, the quantitative aspects of oviposition seem to be variable. For example, the literature reports a range of 1.1 eggs per day to 5.9 eggs per day. Carlson and Hibbs (1962) demonstrated that egg number was affected by host species as well as genetic variation among individuals of the host species. An overall mean for the total egg production was determined to be ca. 200 eggs per female over her life. The oviposition site is less variable, with eggs typically deposited into the plant stems or in the main veins or petioles of the lower leaf surfaces. After hatching, five apterous nymphal stages (described previously) develop by feeding on the underside of the host leaf. Nymphs and adults feed by inserting their piercing-sucking mouthparts into the phloem tissue of the leaf and extracting plant juices.

The lifespan and corresponding total amount of injury produced by one PLH over its life is partially a function of nymphal and adult development time. In Iowa, the complete life cycle lasts 30 to 50 days, with the average duration (days) of each life stage estimated as follows: egg-10, first instar-2.6, second instar-2.3, third instar-2.3, fourth instar-2.5, fifth instar-4.7, and adult-33.5 (Fenton and Hartzell 1920; Deitz et al. 1976). Although these averages are useful for generalizations, the PLH, as with all poikilotherms, develops in relation to temperature. Using a base temperature of 52.5° F, Kouskolekas and Decker (1966) determined that a thermal constant of 435 degree-days was required for PLH development from eggs to peak adult emergence. In addition, they determined that males develop somewhat faster under the same conditions, emerging ca. one day earlier than females. Hogg (1985) confirmed the differences between male and female development rates with life-table studies. Furthermore, he demonstrated that the differences were consistent when populations were reared at different temperatures. Simonet and Pienkowski (1980) refined the degree-day development model to consider the date of first arrival by females in the spring.

The number of generations occurring in any one year varies based on the temperature at the time of development. In northern latitudes, where the PLH cannot overwinter, migrants must recolonize the area each year. In the spring, PLH populations migrate northward from a source region encompassing the southern United States where there is a mean frost-free period of at least 260 days (Decker and Cunningham 1968). Subsequent arrival of the PLH in Iowa is dependent on spring weather systems and not on crop phenology or resident degree day accumulation, as is the situation for many resident species. Weather systems favorable for sustained flight by the PLH include a low pressure center over the Great Plains, a high pressure center over the Atlantic coast, a cold front moving west to east, and an east-west warm front (Pienkowski and Medler 1964). Decker and Cunningham (1967) determined that PLH populations were capable of surviving a long-distance spring dispersal. In addition, they further confirmed that they could not survive the winter in Illinois. In Iowa and other northern states, leafhoppers (as well as other migratory insect species) are washed out of the warm air mass by turbulence and precipitation in late May (Fenton and Hartzell 1920). Immigrants quickly move into late-first-growth or early-second-growth alfalfa, or to other suitable hosts such as potatoes and soybeans. Hence, the timing and magnitude of initial and future population development is highly dependent on synoptic weather conditions in the spring and resident temperatures during development. In most years PLH migrants arrive in Iowa in time to complete two generations and possibly a third or partial fourth.

Many agronomic factors have been identified that hinder or inhibit PLH development and survival. For example, grass species intercropped with alfalfa repel PLH from the field (Smith 1986). In addition, Simonet and Pienkowski (1979) determined that PLH nymphal survival was greatly enhanced with poor harvest practices where leafy material or uncut stems were permitted to remain in the field. Cuperus et al. (1986) quantified this further and documented significant correlations between stubble height and nymphal/adult survival. Beyond these cultural control tactics, potential exists for natural control of PLH populations. Although laboratory studies have identified potential predators of PLH eggs, nymphs, and adults (Martinez and Pienkowski 1982), assessment of the magnitude of natural control in field situations is lacking.

Although the biology of a pest species plays a vital role in determining pest control strategies, ultimately the focus of the management must be on the plant host. Indeed, the host represents the product of an economic enterprise and the pest represents a threat to production. In order to understand the interactions between the host and the pest, knowledge concerning the typical or expected growth pattern is necessary, as well as the mechanisms which may be altered by insect-induced stress. Succeeding components of this review, therefore, focus on the host, which for the current study is alfalfa. In particular, current knowledge concerning the physiological response of PLH injury to alfalfa is reviewed.

Alfalfa Growth and Utilization

Increased interest in soil conservation combined with federal programs to reduce the supply of grain, will likely stimulate an increase in the number of hectares planted to alfalfa. In addition to possessing soil retention qualities, alfalfa has long been recognized as an excellent forage for ruminants. Indeed, if properly managed and supplemented with minerals, alfalfa can provide adequate nutrition as the sole ingredient in many livestock feeding programs (Barnes and Gordon 1972). In the following section, evolutionary and physiological aspects of forage growth and development are presented and related to proper crop management of alfalfa.

Evolutionary perspective

The Random House dictionary defines forage as: "food for horses and cattle". This simplistic characterization grossly underestimates the complex considerations associated with culturing a forage for economic purposes. Nevertheless, with the suggestion that herbivores consumed forages long before man's attempts to domesticate animals, it becomes evident that counter adaptive forces have occurred, and continue to occur, between forages and "foragers". In fact, this coevolution has likely had a significant impact on the characteristics of "modern" forage and ruminant species. The notion that organisms interact and affect each others survival and development has been recognized for a long time (Darwin 1859). The realization that this could occur at the Kingdom level of the phylogenetic tree, however, is relatively recent (Gilbert and Raven 1975). Inasmuch as man domesticated both plant and animal species for his benefit, it is appropriate that the mechanisms mitigating against development of "the perfect feed" be investigated and placed in perspective to current agronomic practices.

The simplifying concept of Van Soest (1982) that all plant metabolic products are considered as an aggregate and subsequently partitioned as going to either a reserve mechanism or a resistance mechanism will be adopted (Fig. 1). Excluding the breeding efforts of the past 100 years or so, plants have developed for their own benefit, which is to avoid destruction from all adverse elements. In particular, adverse elements may be from the abiotic environment or the biotic environment, including pathogen infection and herbivory. Van Soest regards the partitioning of nutrients and metabolic energy to retard abiotic/biotic destruction as **resistance**. By contrast, plant **reserves** represent the portion of metabolites remaining after resistance mechanisms are in place. In annual grain crop situations, the reserves are converted to seeds and used for propagation of the species. In the situation of perennial forages (e.g., alfalfa), reserves also are necessary for foliage regrowth following grazing or harvesting. The nutritive value of a forage is primarily determined by its composition; consequently, a sequence of cause-effect relationships exists among environment, plant response,

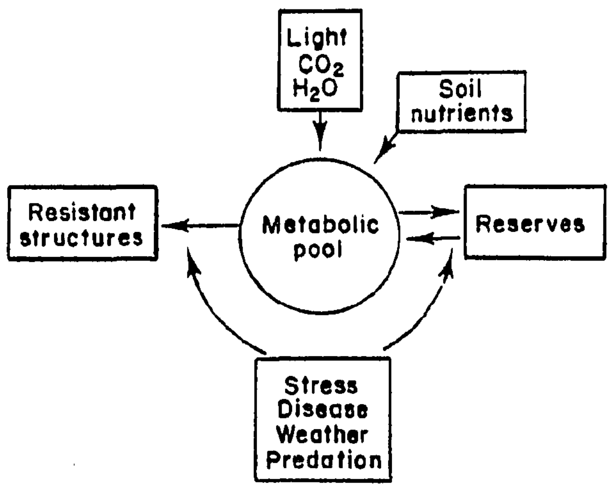


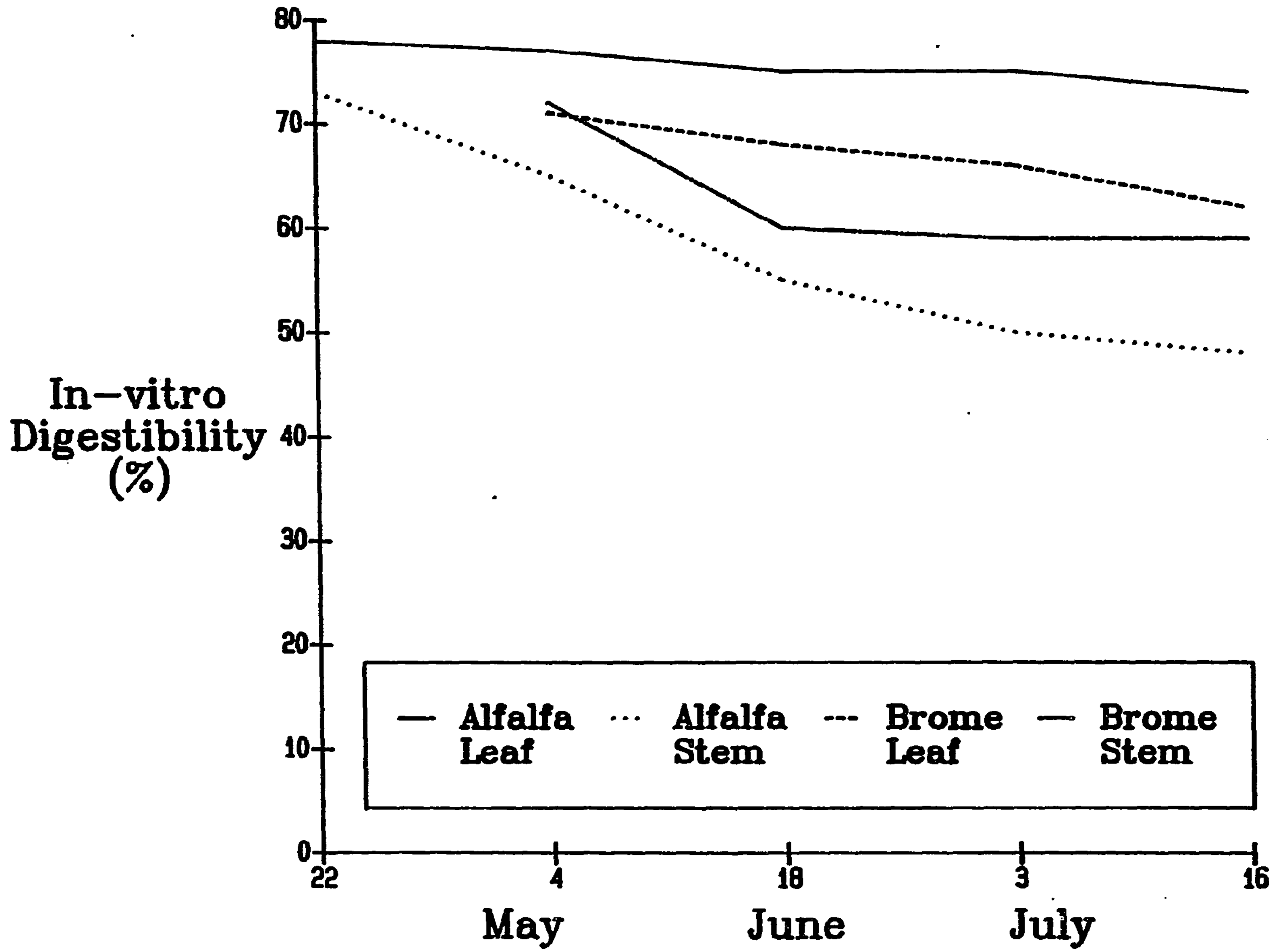
Figure 1. Relationship of environmental factors (biotic and abiotic) to plant metabolic components (after Van Soest 1982, p. 58)

composition, and nutritive value (Van Soest 1982).

Secondary cell-wall formation and concomitant lignification has, by far, been the most significant resistance mechanism evolved by plants. As young plants grow vegetatively they increase in size by adding new cells and expanding existing cells (Brown et al. 1972). This process acts to hold the photosynthetic tissue in a position to compete for photosynthetically active radiation (PAR). Once plant cells have expanded, secondary cell wall formation occurs (Grove and Carlson 1972). This process involves covalent bonding, via lignification, of plant cellulose and hemicellulose into a rigid and dense chemical matrix. Not coincidentally, the lignified tissue is relatively "resistant" to maceration and digestion by ruminants and insects alike. The proportionate emphasis that a plant species places on resistance vs. reserves often depends upon the environment in which it exists. For example, tropical plant species almost invariably allocate more of their metabolic pool to resistance than temperate species do (Minson 1971). The harsh environment (both abiotic and biotic) of the tropics necessitates this partitioning. The relative degree of resistant vs. reserve components within a plant determines its value as a forage (Van Soest 1982). High concentrations of cell wall and lignification limit the quality of a forage so that available energy and nutrition per volume consumed is reduced as plant maturity encroaches. Ruminants, even with their specialized digestive systems, are unable to fully utilize the energy of cellulose and hemicellulose once it is bonded through lignification (Mohrenweiser and Donker 1968; Spahr et al. 1961; Weir et al. 1960).

Component plant parts differ in their degree of lignification and cell-wall concentration (Mowat et al. 1965). Broadleaf species typically possess heavily lignified support (stem) components, with less lignified leaves. As a result, the lignin and cell-wall percentage of leaves remains relatively constant with maturation (Luckett and Klopfenstein 1970). Stems, on the other hand, contain ca. 75% of the cellulose or crude fiber of the plant, and therefore are only partially digestible. Inasmuch as the lignin percentage of stems is often more than three times that of leaves, it is common to characterize leguminous forages by their leaf:stem ratios (Barnes and Gordon 1972). In the situation of grass forages, however, the leaf:stem ratio is less revealing because leaves do provide some support for the plant and require partial lignification. Figure 2 illustrates the differences among component parts for typical grass species vs. alfalfa. In general, the rate of decline in forage digestibility for grass components is intermediate to the rate of decline for alfalfa leaves and stems. In many situations the objectives of forage cultivar development are exactly opposite of evolutionary survival adaptations. For example, high levels of lignification are deleterious to maximal ruminant intake and digestibility of a feed; but, the high level of lignification has likely played an important role in the survival of the species under competitive situations.

Figure 2. In vitro digestibility of leaf and stem components for alfalfa and brome grass averaged over three years (after Mowat et al. 1965)


In–vitro Digestibility (%)
80
70
60
50
40
30
20
10
0
22
4
18
3
16
May
June
July
Alfalfa Leaf
Alfalfa Stem
Brome Leaf
Brome Stem

Forage growth and biomass development

Paramount to the agronomic management of alfalfa is the relationship of shoot regrowth and canopy development to yield and quality. Regrowth, a phenomenon somewhat unique to perennial species, requires substantial reserve energy to fill a deficit established with the loss of current photosynthesis (Brown et al. 1972). The duration and magnitude of regrowth, however, is a function of the crops ability to re-establish a self supporting energy mechanism, i.e., photosynthesis. Insect stress can and will affect regrowth and canopy development in alfalfa (App and Manglitz 1972; Buntin 1984). In order to understand how and why this occurs, a review of the pertinent aspects of alfalfa regrowth physiology is presented.

Root carbohydrates Regrowth of alfalfa following defoliation is facilitated by root stores of carbohydrates, primarily starch, with sucrose probably serving as the primary transport carbohydrate within the plant (Nelson and Smith 1968b). These nonstructural carbohydrates, which accumulate in the crowns and taproots of the plant, represent Van Soests' (1982) pool of reserve metabolites discussed previously. The cyclic decline in root carbohydrates has been documented in several studies (Grueb and Wedin 1971; Smith 1972; Nelson and Smith 1968b; Robison and Massengale 1968), but remains the topic of investigation in relation to plant stress.

In addition to root carbohydrates, photosynthesis by stubble leaves plays an important role in regrowth (Hodgkinson 1973 and 1974). Following defoliation, a rapid decline in stored carbohydrates occurs until ca. 15 to 20 days postcutting. At this time, the roots decline in weight as their reserves are mobilized and used for foliar growth. Root carbohydrate levels begin to increase within ca. four weeks following cutting and reach maximal levels at about full bloom. The specific time required for carbohydrate replenishing depends on many factors (Bolton 1962; Smith 1975), including: (1) frequency and intensity of cutting, (2) stage of maturity at cutting, (3) climate.

Smith and Silva (1969) determined the relative contribution of current photosynthesis to be significant after the first week of regrowth. Specifically, the contribution of current photosynthesis was determined to be 0, 52, 70, and 93% of the total plant weight on days 7, 14, 21, and 42 following defoliation, respectively. In addition, they noted that root nitrogen declined significantly in proportion to carbohydrate depletion, suggesting that stored nitrogenous compounds represent the primary source of regrowth nitrogen. Hodgkinson (1973), however, demonstrated that canopy demand for nitrogen was adequately met by current root uptake and not by remobilization of stored root nitrogen.

Studies utilizing radioactive carbon (^{14}C) clearly demonstrated the utilization of accumulated carbohydrates in alfalfa regrowth (Hodgkinson 1969; Pearce et al. 1969; Smith and Marten 1970). These studies identified a sigmoidal rate of decline in carbohydrate depletion, with the maximal rate of starch breakdown occurring between days 3 and 15 post harvest. In addition, they determined that it was not until day 21 that the net flow of ^{14}C was from the foliage to the roots. As photosynthetic area increased, the net flow of ^{14}C added to the roots also increased so that on day 35 ca. 36% of the 24-hr photosynthate production was translocated to the roots and converted to starch. The three-day lag before starch utilization was presumed to be the time needed for the plant to switch from starch synthesis to starch mobilization following harvest (Pearce et al. 1969). Therefore, starch utilization occurred from day 3 to day 15, and starch synthesis began on day 21 and continued until the next cutting.

Buntin (1984) determined that insect-induced defoliation delays of seven days or more reduced dry matter by slowing stem growth rate. He further observed an overall change in plant partitioning to minimize the adverse effects of stubble defoliation by maintaining growth rates of leaf mass and area at the expense of support-structure growth. The altered partitioning was believed to be the result of a depletion of stored carbohydrates.

The role of stubble leaves in regrowth of the plant is unclear. Hodgkinson et al. (1972), in greenhouse studies, concluded that stubble leaves were beneficial to the role of early regrowth and should be retained. Fuess and Tesar (1968), however, previously demonstrated that stubble leaves were only capable of producing a fraction of the energy that new growth could produce, and the former were likely of no consequence for regrowth. Brown et al. (1972) concurred and further stated that the net CO_2 exchange rates of stubble leaves in the field were low enough to be a liability rather than an asset to plant regrowth. In light of this, as well as the fact that Hodgkinson and his colleagues used greenhouse conditions where the lower portions of the canopy tend to remain more "active", it seems likely that the value of stubble leaves is low under field conditions.

Canopy development With the determination that root carbohydrates serve as the source of initial regrowth energy, the specific utilization of this energy should be focused on. For presentation purposes, alfalfa canopy development can be considered to have three phases of growth: (1) bud and shoot initiation, (2) vegetative growth, and (3) reproductive development. For agricultural production of alfalfa, the first two growth phases (and bud stages) require primary consideration, with the understanding that all the events which precede seed production occur to facilitate this final stage.

The period of stem initiation, which determines the potential stem density for the crop, is critical for future canopy development. As mentioned previously, this phase is supported almost entirely by root carbohydrates. Bula and Hintz (1978) determined that 375 stems/m^2 represented a critical level to achieve maximal yields. In fact, the number of stems per plant varies inversely with plant density to negate much of the advantage of additional stems per plant. Hodgkinson (1973) determined that 75% of all new shoots on plants cut within 15 cm of the soil arose less than 2.5 cm from the crown of the plant. Hence, increased cutting height above ca. 3 cm does not enhance regrowth capability of the plants (Smith 1972). Temporally, the rate of shoot initiation is rapid, with most growth occurring within seven days of cutting. Shoots beginning growth within the first week of regrowth contributed about 80% of the final yield at harvest (Leach 1968, 1969, and 1970). Shoots that initiated growth after the first week were usually few in number, slower in their rate of growth, and contributed little to final yield. It seems, then, that management practices should attempt to maximize the number of shoots that initiate growth soon after cutting.

Vegetative growth is the essence of forage production. Indeed, the overall strategy of forage production should be to maximize vegetative growth and minimize maturation, which involves a greater degree of lignification. This optimization requires intense harvest management. Alfalfa management has been studied under 2-, 3-, and 4-cut systems in the midwestern U.S. by Fuess and Tesar (1968), Grueb and Wedin (1971), Nelson and Smith (1968a), and Wilfong et al. (1967). The consensus of these works demonstrates that leaf area accumulations were low during the first 7 to 10 days following harvest. Following this period, however, the rate of increase was linear and occurred until flowering. Values for leaf area index (LAI) and yield were highest for spring growth and declined for succeeding harvests. The point of 95% irradiance interception for spring growth was achieved ca. three weeks before flowering, which suggested that crop growth rate (CGR) was maintained at maximal levels for that time. The higher temperatures of summer growth accelerated maturity to the degree that 95% irradiance interception was not achieved before flowering (Nelson and Smith 1969).

Alfalfa leaves are not uniform in their rate of photosynthesis. For example, alfalfa leaves taken from the bottom of alfalfa plants in a four week old stand were about half as efficient in CO_2 uptake as top leaves

(Brown et al. 1966). Wolf and Blaser (1972) determined that the photosynthetic differential was the result of a decline in leaf efficiency and specific leaf weight of lower leaves due to reduced penetration of photosynthetically active radiation. Additional factors, such as varying leaf size, also offset the rate of photosynthesis and may further distort the relationships between canopy photosynthesis and final yield (Bhagsari and Brown 1986). Ultimately, the impact of an external stress on the leaf component of alfalfa depends upon the relative value of leaves, both to the plant and the animal, which have been altered.

Alfalfa quality The dual production objectives of high yield and high quality necessitate compromise. Indeed, from a management perspective, forages do not conform to a simple yield only criterion. A contributing factor in this dilemma is the fact that "quality" is an abstract consideration. The abstractness is a result of the final use of the forage as a commodity and the debate/confusion over the components related to quality. In other words, the definition of quality varies with application and implementation. Nevertheless, certain characterizations regarding alfalfa quality are widely recognized as indications of final utility to the animal. In general, the character and nutritive value of feeds and forages are determined primarily by two factors: proportion of plant cell wall and its corresponding degree of lignification (Van Soest 1982).

Feeding value to the animal is limited by the daily intake of digestible nutrients and the efficiency with which these digested nutrients can be used for the necessary body processes (Barnes and Gordon

1972). Particular emphasis is given to an expression of available energy because forage rations are frequently limited in energy content rather than nutrition (Gordon et al. 1961). Specifically, characteristics that enhance digestibility or intake of the plant are favorable.

Digestibility Ruminants, even with their specialized digestive system and microbial symbiosis, are not capable of totally converting plant material into energy. The percent digestibility represents the proportion of a feed that is available for absorption by the ruminant. Digestibility not only varies among plant species but also among plant parts and plant phenology. In each instance, the primary factor regulating digestibility of a feed relates to the level of lignification at the time of consumption. For example, alfalfa fed to a ruminant before bloom is much more digestible than the same growth after it reaches reproductive maturity. Lignin acts to limit the extent of digestion but has comparatively little influence on the rate of digestion (Smith et al. 1971). The dense cell-wall development and lignification, which dominates mature stem growth, is not susceptible to the enzymatic action of gastric chemicals or symbiotic organisms in the rumen. However, alfalfa leaves, which maintain a lower cell-wall concentration, maintain a high level of digestibility.

Assays to determine the relative digestibility of a forage species have been developed. In vivo tests measure the amount of feed input and the amount of animal excrement, and then determine digestibility by calculating the percentage of consumption not excreted. The feces contain not only the undigested diet but also metabolic products including bacteria and endogenous wastes from animal metabolism. Consequently, apparent digestibility can be considered the balance of the feed less the feces, while true digestibility is the balance between the diet and the feed residues in the feces, exclusive of metabolic products. A more practical way of determining digestibility involves in-vitro tests with rumen fluid. Here, a known amount of forage is subjected to rumen fluid digestion under controlled conditions, and the remaining forage represents the undigestible portion. The most common in-vitro technique to determine digestible dry matter was developed by Tilley and Terry (1963) and incorporates a second stage digestion with pepsin to simulate gastric digestion. The measurement of acid-detergent fiber (ADF) also has proven to be indicative of digestibility. With this technique, an estimation of the amount of cellulose and lignin in the plant is made using an acid-based solution (Van Soest 1982). The value of this test lies in its high correlation with digestibility values. In addition, the ADF procedure is considerably less expensive to perform than the in-vitro rumen assays. Ultimately, digestibility is a measure of the availability of feed to rumen microorganisms or animal digestive enzymes. Thus, in-vitro methods are related more to true digestibility than to apparent digestibility.

Intake   Intake of a feed is an aspect of forage quality, the species of the consumer, the animals physiological status, the animals energy demand, and the animals individual preference (Van Soest 1982). It is often assumed that intake and digestibility of forages are directly related. In fact, intake is dependent upon the structural volume and, therefore, cell-wall content, while digestibility is dependent upon both cell wall and its availability to digestion as determined by lignification and other factors.

In high quality feeds (e.g., grain concentrates), metabolic requirements tend to be limiting. This metabolic limiting situation is referred to as the set point. In most instances, forages never reach a metabolic limiting situation because limiting factors of feed quality impose a lower level of feed intake. Although palatability may play a role in intake, a larger part relates to the rate at which a feed can pass through the digestive system (Barnes and Mott 1970). The total advantage of high quality alfalfa goes beyond the digestible nutrient content and is compounded by a potential for being consumed at higher levels, a faster rate of digestibility, and perhaps a more efficient conversion of digested energy to productive energy (Barnes and Gordon 1972).

For forages, the association with animal intake depends on plant structure. Cellulose, for example, is more closely associated with intake than digestibility, while lignin is more closely related to digestibility (Barnes and Gordon 1972). The total cell-wall concentration (versus cell soluble concentration) is generally considered the most consistent cell fraction related to intake. This is not unexpected because the cell wall contains structural components of the plant within which all other components are contained. Apparently, the expression of animal desire for feed is greater at lower cell-wall concentrations. Moreover, if the principal effect of rumination is to collapse and release the highly digestible intercellular spaces within the forage cell walls, perhaps a high level of cell-wall content is counterproductive (i.e., the period of rumination is extended) to this objective (Van Soest 1982). Regardless of the mechanism, voluntary intake may account for two-thirds of the variability of animal performance (Byers and Ormiston 1962). For laboratory analysis, neutral-detergent fiber (NDF) assays will determine the amount of principal cell-wall components (cellulose, hemicellulose, lignin) present in the forage (Van Soest 1982). The NDF techniques are similar to ADF procedures except a neutral solution (pH ca. 7.0) is utilized for the former.

For most situations, forage quality is determined on a total-herbage basis, although in-vitro digestible dry matter (IVDDM) varies among plant parts. Buxton et al. (1985) documented these differences and further determined the vertical rate of change in IVDDM for stems and leaves. The lower stem component was found less digestible than the apical portions. Moreover, they determined that leaf:stem ratio's were significantly lower in the basal portions of the crop. In a separate study, Buxton and Hornstein (1986) determined that cell-wall concentration was low in leaves and greatest in the basal stem segments. Hence, as a practical concern, the value of the lower portions of an alfalfa canopy is reduced per unit of mass.

Crop and Pest Management of Forages

As agricultural commodities, forages are unique. The fact that forages have poorly defined exchange markets and are commonly grown as an input for on-farm livestock production severely complicates traditional pest-management decision-making algorithms. The primary reason for this complication is the difficulty associated with assigning a dollar value to the crop. In addition, with the situation of PLH-induced injury, the exact crop response is largely unknown. The following review introduces some economic concepts as they apply to alfalfa production, with the further application to pest management strategies for insects.

Objectives of alfalfa production

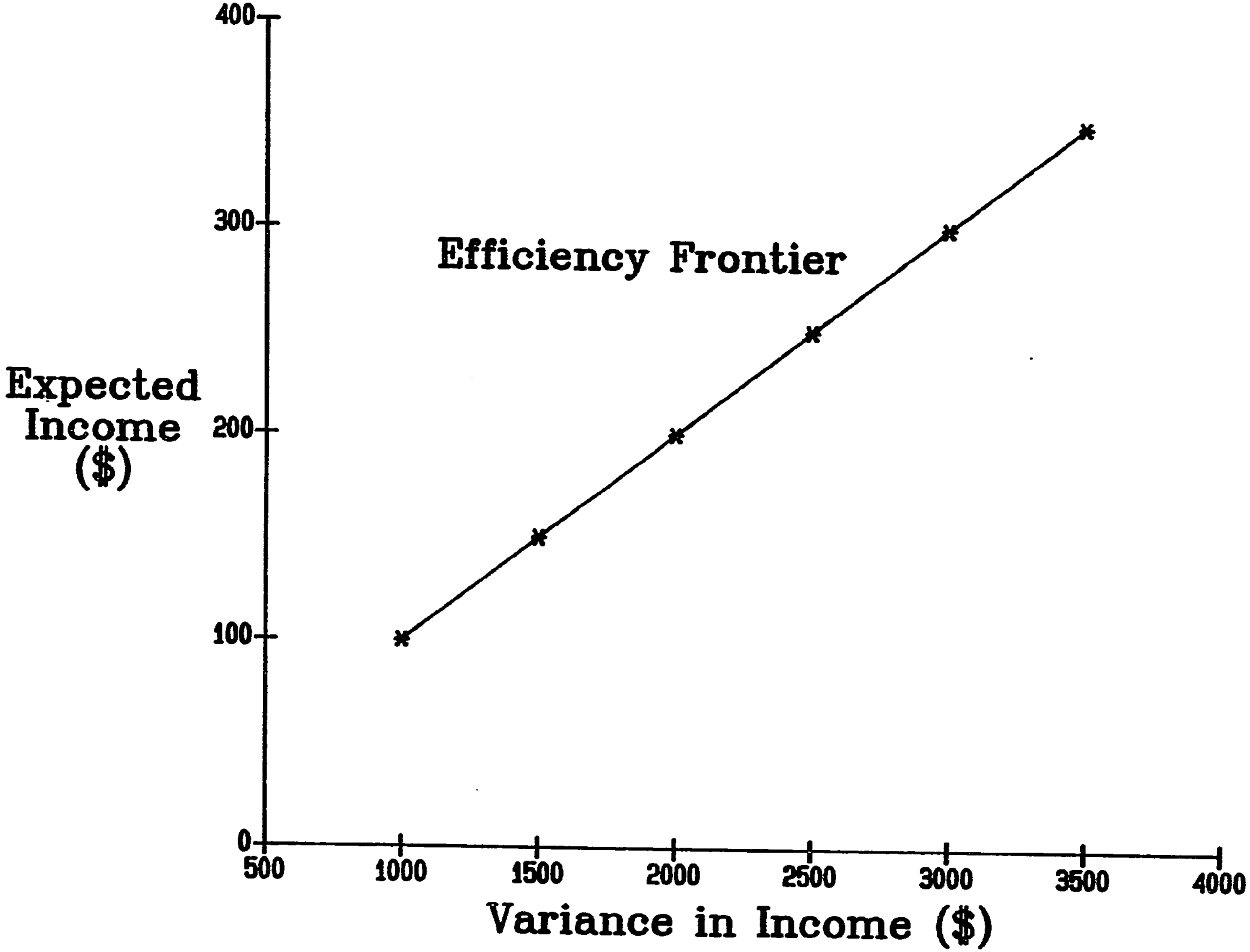
Forages are indispensable as feeds for livestock. Although grain crops will, on average, provide a higher rate of gain per day, the fiber provided by forages is necessary to maintain the microbial flora in the rumen and hence the health of the animal. Forages should not be totally eliminated in animal rations but should be utilized as a source of protein, energy, and fiber within a least-cost rationing strategy. Therefore, the value of alfalfa from one application to another will vary in relation to its proportionate contribution to the final formulated feed.

As an input, specific properties of alfalfa may be emphasized for some enterprises and less emphasized in others. For example, dairy producers commonly use alfalfa as a source of energy and protein to capitalize on its nutritional value, but beef producers are attracted to the high yields that alfalfa generates over several harvests. Both types of production require sufficient quality and quantity but in different proportions and degrees of importance. The utility of alfalfa should be envisioned as its usefulness to the producer, representing a proxy for evaluating both yield and quality as a single parameter. Each producer, therefore, can weight his/her own relative benefits from the quantity and quality aspects of the crop and determine its corresponding utility.

As a business goal, the input costs of producing any commodity should be minimized to the degree that they do not constrain production. In addition, the variation in the income from production should also be minimized to insure that cash flow demands are satisfied as needed. Alfalfa, as an input itself, should conform to these business axioms. In other words, the input commodity should be produced as cheaply as possible, with minimal deviations in yield and quality over time. The requirement on production variance represents the economic demand for pest management, while the minimal-cost requirement represents the need for efficient implementation of control tactics. In order to design crop and pest management strategies, the consequence of PLH feeding on the yield and quality of alfalfa must be elucidated in relation to the valuable characteristics of alfalfa.

Figure 3 represents a trade-off relationship for maximizing production and minimizing risk. This general characterization, commonly referred to as an Expected Income - Variance in Income Frontier (E-V Frontier), or efficiency frontier, demonstrates the need for compromise in order to achieve exclusive goals (Boehlje and Eidman 1984). For example, totally neglecting pests <u>may</u> result in the highest possible income if pests happen to remain below economic levels for that period. If, however, pests become a problem and are left unchecked, then net

Figure 3. Generalized efficiency frontier for determining the maximum expected income for any given level of variance, or alternatively, the minimum level of variance for any level of expected income (after Boehlje and Eidman 1984, p. 464)


Efficiency Frontier
Expected Income ($)
Variance in Income ($)
400
300
200
100
0
500
1000
1500
2000
2500
3000
3500
4000

income will likely be low. The trade-off for obtaining maximal yields is the possibility, or risk, of very low yields. With the opposite strategy, control tactics are applied without regard to pest density and the opportunity to maximize income is reduced to situations where pests are particularly severe. The logical compromise is to monitor pest populations each year to eliminate both unfavorable scenarios. Exactly where a producer lies on the E-V Frontier depends on personal attitudes toward risk. Although many growers are considered to be risk averse, there is no reason to assume that this business posture is the "best" attitude. In any case, knowledge about a pest and its association with the crop provides a basis for making pest management decisions.

Nature of PLH-induced injury to alfalfa

Although the PLH has long been considered a pest of alfalfa, the exact mode of injury has not been determined. Plant injury can be seen as a discoloration or yellowing in the tips of the leaves which progresses to form a complete V-shaped chlorosis over much of the leaf. This injury is symptomatically referred to as "hopperburn". Injury to the plant seemingly is in the form of phloem destruction and clogging by debris during the feeding process of repeatedly inserting the stylet. In addition, as the PLH feeds, a stylet sheath forms which further blocks the phloem and xylem. Smith (1933) determined that the sheath was composed of protein produced entirely by the insect. Evidence exists to suggest that the PLH secretes a toxin into the leaves of some hosts (Granovsky 1930; Montieth and Hollowell 1929; Medler 1941); but, Smith and Poos (1931) found no evidence of a toxin in legume hosts. Based on this study, they concluded that mechanical obstruction of the phloem and xylem was the predominant type of injury. Additional work by Medler (1941) and Putnam (1941) bear out this conclusion.

Numerous studies have been conducted to establish the pest status of PLH on alfalfa. In many instances, the PLH represents the only insect species capable of causing significant economic losses to alfalfa (Smith and Ellis 1983). Reductions in dry matter and plant height are among the most commonly documented yield responses to PLH feeding (Faris et al. 1981; Smith and Ellis 1983). Kouskolekas and Decker (1968) suggest that the true damage potential for this species is a function of the level of infestation and crop profile as measured in stem height. They determined that PLH populations of 2.8, 5.6, 11.1, and 22.3 per m^2 on alfalfa 6.4-cm tall reduced yields 45, 57, 79, and 95%, respectively; whereas, on alfalfa 20.3-cm tall, the same populations reduced yields by only 3, 16, 34, and 47%. Cuperus et al. (1983) estimated economic-injury levels at 0.40, 0.32, and 0.50 PLHs per pendulum sweep when alfalfa has reached 5, 12, and 17 cm of regrowth, respectively. Infestations that exceed economic-injury levels may affect regrowth by causing shorter stem length and shorter internodes (Medler 1958).

In some instances, the physiological basis for yield loss has been investigated (Ladd and Rawlins 1965; Womack 1984). Ladd and Rawlins (1965) noted a long-term reduction of 30 to 40% in photosynthetic activity and a short-term decrease in respiration following PLH feeding. These physiological effects and the resultant decreases in dry matter yield may be additive with deleterious effects from other alfalfa pests

(Wilson et al. 1979).

The quality of harvested alfalfa is reduced by excessive PLH feeding. Kindler et al. (1973) reported reductions in carotene content ranging from 45 to 78% and in protein from 15 to 24%. In a similar study, Smith and Medler (1959) found reductions in the percentages of protein, ash, calcium, and phosphate; increases in fat and nitrogen-free extract were also noted. Hower and Muka (1975) and Faris et al. (1981) substantiated reductions in protein and mean digestible dry matter. Although alfalfa quality reduction as a result of PLH feeding is well documented, this aspect of damage is poorly integrated into the decision-making process for control. In addition, the documented losses in leaf protein have not been related to limiting levels of animal nutrition.

The damage function(s) for alfalfa, as with most pest/host relationships, varies dramatically in relation to environmental conditions. Although many of these relationships have been investigated, the concentration is frequently on pest density rather than host response, which clouds the interpretation regarding physiological mechanisms of the plant. Moreover, the yield vs. quality production objectives often respond differently with additional environmental stress.

Objectives of alfalfa pest management

Alfalfa pests should not be controlled at all costs. Rather, they should be managed when their collective injuriousness to the crop equals or exceeds the cost of their control. Economically, this represents a break-even point and is best expressed with an economic-injury level

(EIL, Pedigo et al. 1986). The EIL is the level of pest-induced injury which equals the cost of alleviating further injury and has four primary variables that must be determined before calculation: (1) control costs; (2) market value, (3) injury per insect, and, (4) damage per unit of injury. Equation 1 presents the general formula for an EIL utilizing the four primary variables.

$$\text{EIL} = \frac{\text{Control Costs}}{\text{Market Value x (Injury/insect x Damage/injury)}}$$

For PLH management on alfalfa, three of the four primary variables are less than straightforward. Control costs represent the variable inputs, including materials and labor, necessary to control further PLH induced injury to alfalfa. Each of the remaining EIL variables require additional consideration before their determination.

For most agricultural commodities the market value determination for EIL's involves referencing daily market prices, or substituting target prices. Although the price fluctuates, at least a concrete value can be determined. For forages, however, a clearly defined market does not exist. Instead, subjective values for hay or empirical considerations, which are difficult to define, must be used. One method of determining the value of alfalfa is to calculate replacement costs with a substitute feed such as soybean meal (Craven and Hasbargen 1979). In protein equivalents, this is a valid procedure. For alfalfa management however, the technique may be flawed. For example, once a commitment is made to produce a hectare of alfalfa, then fixed and variable input costs are channeled to that production. Furthermore, substitution calculations consider only the variable costs, but neglect to incorporate the opportunity costs of the land, labor, or capital previously invested in the alfalfa. Moreover, final crop injury cannot be determined a priori, so the management focus should remain on protecting the alfalfa hectare rather than replacing the harvest with a substitute feed.

PART I. GROWTH AND BIOMASS DEVELOPMENT OF STEM AND LEAF COMPONENTS SUBJECTED TO FEEDING BY POTATO LEAFHOPPER

ABSTRACT

Experiments were conducted to investigate the impact of potato leafhopper (PLH), *Empoasca fabae* (Harris), feeding on the growth and biomass development of alfalfa, *Medicago sativa* L. Three field trials were conducted in 1984 and 1985 near Ames, Iowa on 'Blazar' alfalfa using caged populations of PLH. The experimental design consisted of a split-plot in time, with whole-plots representing a factorial arrangement of PLH density and infestation period. Four densities (0, 50, 100, and 200 per m^2) of PLH adults were collected from surrounding hosts and infested at 0-days and 14-days following the first harvest. Cages were sampled weekly (subplots) by measuring stem density and removing stem samples for PLH density measurements and plant growth analysis. Analysis of data consisted of an analysis of variance, followed by orthogonal comparisons.

Stem density was not altered by PLH-induced stress. In contrast, stem height was severely reduced at all infestation levels. The reductions were seen at both infestation periods and first appeared within seven days after feeding. The leaf component was affected less. However, when leaf area values were adjusted to include only non-chlorotic tissue, the leaf area index was significantly reduced for infested plots. Differences in individual leaf weights were not observed.

Overall biomass yield was reduced in the infested plots. Closer observation of crop, stem, and leaf growth rates indicated that the injured plants were rapidly compensating for the initial injury just

before harvest. Measurements for net assimilation rate confirmed these observations. These results indicate that cutting early to reduce PLH losses may prevent the plant from compensating for early losses in biomass.

INTRODUCTION

The potato leafhopper (PLH), Empoasca fabae (Harris), has long been considered a serious pest of alfalfa, Medicago sativa L. This pest migrates annually from the southern United States and arrives in the North Central United States during the first regrowth period of alfalfa. Immigrants quickly colonize late-first-growth or early-second-growth alfalfa, or other suitable hosts such as potatoes and soybeans. After mating, females deposit eggs into plant stems or in the main veins or petioles of the lower leaf surfaces. After hatching, five apterous nymphal stages develop by feeding on the underside of the host leaf. Nymphs and adults feed by inserting their piercing-sucking mouthparts into the phloem tissue of the leaf and extracting plant juices.

Although the PLH is considered a pest of alfalfa, the exact mode of injury has not been elucidated. Plant injury can be seen as a discoloration or yellowing in the tips of the leaves which progresses to form a complete V-shaped chlorosis over much of the leaf. The mechanism for injury is believed to be destruction and clogging of the phloem during feeding by repeatedly inserting the stylet. Many times, the PLH-induced injury results in reductions in dry matter and plant height (Faris et al. 1981; Smith and Ellis 1983), as well as reductions in forage quality.

In some instances, the physiological basis for yield loss has been investigated. Ladd and Rawlins (1965) noted a long-term reduction of 30-40% in photosynthetic activity and a short-term decrease in respiration following PLH feeding. These physiological effects and the resultant decreases in dry-matter yield may be additive with deleterious effects from other alfalfa pests (Wilson et al. 1979). The damage function(s) for alfalfa, as with most pest/host relationships, varies in relation to environmental conditions. Although many of these relationships have been investigated, the concentration is frequently on pest density and final yield rather than host response, which clouds the interpretation regarding physiological mechanisms of the plant. Yield represents an end point subject to the interactions among the plant, the insect, and other stressors, and often provides only some evidence of the physiological response of the crop to injury.

Alfalfa regrowth requires substantial amounts of reserve energy in the form of root carbohydrates (Brown et al. 1972) to fill a deficit established with the loss of current photosynthesis. The duration and magnitude of regrowth, therefore, is a function of the crops ability to reestablish self supporting levels of photosynthesis. With root carbohydrates serving as the source for initial regrowth energy, the specific utilization is for: (1) bud and shoot initiation; (2) vegetative growth; and, (3) reproductive development.

Field studies were designed and conducted with the objective of determining the effect of PLH-induced stress on the crop-physiological processes of alfalfa regrowth. In particular, the stem and leaf components were monitored separately to distinguish individual responses to PLH feeding initiated at two times within the regrowth period. The emphasis here is on crop biomass development of plant parts and is supported with growth and partitioning analysis to identify the temporal dynamics of host response. The data and conclusions of this study should assist in developing pest management strategies for this pest with a greater understanding of host response.

MATERIALS AND METHODS

The experiment consisted of one field trial in 1984 and two field trials in 1985. All plots were established on a Webster silty clay loam (fine loamy, mixed, mesic Typic Haplaquoll) at the Johnson Research Farm located ca. 2.5-km south of Ames, Iowa. A 2.3-ha field was planted to 'Blazar' alfalfa using a 17.5-cm grain drill planter calibrated to deliver 15.7 kg of seed per hectare. The field was planted on 25 April 1984, following an application of Eptam® (20 April 1984) to suppress grass weed species during establishment. Prior to growth each year, the field was topdressed with 135 kg/ha of P and 225 kg/ha of K. Management practices typical of alfalfa production in central Iowa were followed and daily temperature and rainfall data were obtained from National Oceanic and Atmospheric Administration weather station 0200-05 (positioned ca. 12 km west of the Johnson Research Farm).

In the 1984 trial, the field remained undisturbed during the first regrowth period and was cut to a height of 6.4 cm on 14 July. All plant material was immediately removed and the plot area was raked to remove any excess trash and stubble. Thirty-two plots (1 m x 2 m) were established according to a randomized complete block design with four replications. Each of the four blocks consisted of a factorial arrangement of four densities of PLH (0, 50, 100, and $200/m^2$) and two infestation periods (1 day following harvest [early or A], and 14 days following harvest [late or B]). Immediately after cutting, a Saran® mesh cage (1 m x 2 m x 1 m tall) was placed over each plot (randomly determined) designated as infested early.

Adult PLH were collected using a D-Vac® vacuum insect net placed over nearby glabrous soybean (isoline of 'Clark'). Samples were collected in mesh bags and returned to the laboratory where they were placed in plexiglass cages and aspirated into glass test tubes by quantities of 50. Each plot then was infested with the required number of test tubes (0, 2, 4, or 8 test tubes for 0, 50, 100, or 200 PLH per m^2, respectively). Cages were left covering the plots for 14 days to allow for oviposition. After this period, they were relocated to the late infested plots and the infestation procedure was repeated, with all cages removed following this second 14-day oviposition period. Restricting the caged period to 14 days was deemed necessary to eliminate or reduce the shading effect on plant growth and development. Resident populations of PLH were monitored to insure that transitory feeding did not alter the plot densities within the experimental area of the field. In addition, the glabrous soybean planted in the distant perimeter of the plot area were believed to attract immigrants away from the alfalfa plantings.

Plots were established and maintained for two field trials in 1985 in the same fashion as described for the 1984 trial. The first trial in 1985 (referred to as 1985A) was infested on 2 July and the second trial (1985B) was infested on 31 July. All field trials were established within the same field and on second regrowth, but at different locations within the 2.3-ha field.

A split-plot in time was superimposed, with whole-plots representing the factorial arrangement of PLH densities and infestation periods. Subplots represented PLH and destructive plant samples taken weekly from one-half of the plot area (1 m x 1 m). The remaining portion of each plot was utilized for stem density counts on a weekly basis and for final yield measurements. The destructive sampling consisted of collecting three individual bouquets of stem samples.

A 9-stem bouquet was collected from each plot and carefully placed in a carton with dichlorovos-impregnated insecticide strips (Simonet et al. 1978). The PLH nymphs dislodged within 48 hours and were recorded. A second sample, consisting of 25 stems, was collected and returned to the laboratory for physical measurements. Specifically, the following growth and yield characteristics were measured: stage of morphological development (Kalu and Fick 1981), stem height, stem weight, number of main stem nodes, number of healthy and injured leaves, leaf area of healthy and injured leaves as determined by a LiCor® model 3000 planimeter, dry weight of healthy and injured leaves. In addition, the injured leaves were analyzed with a video-contrast area meter to determine the proportion of the leaf which exhibited chlorosis. The final sample bouquet, consisting of 25-stems, was dried and prepared for future quality assay.

Procedures for Statistical Analysis

All measurements of plant growth, including calculated values (see Appendices A and B), were analyzed by year and sample date with an analysis-of-variance (ANOVA) procedure and a least-significant-difference determination. Means for plant parameters for this analysis can be found in Appendix C. An ANOVA over all years by sample date (days 7, 14, 21, 28, and 35) and at second harvest (2-Har) was also conducted, with whole-plot differences determined by orthogonal comparisons. This procedure was deemed to be the most efficient method of determining class differences (e.g., early vs. late infestation) among the whole-plot combinations. Specific comparisons used as contrasts (labelled as infestation period: PLH densities) were: A: 0 versus 50-200, A: 0-100 versus 200, A: 0 versus 50, B: 0 versus 50-200, B: 0-100 versus 200, B: 0 versus 50, A versus B: 50-200.

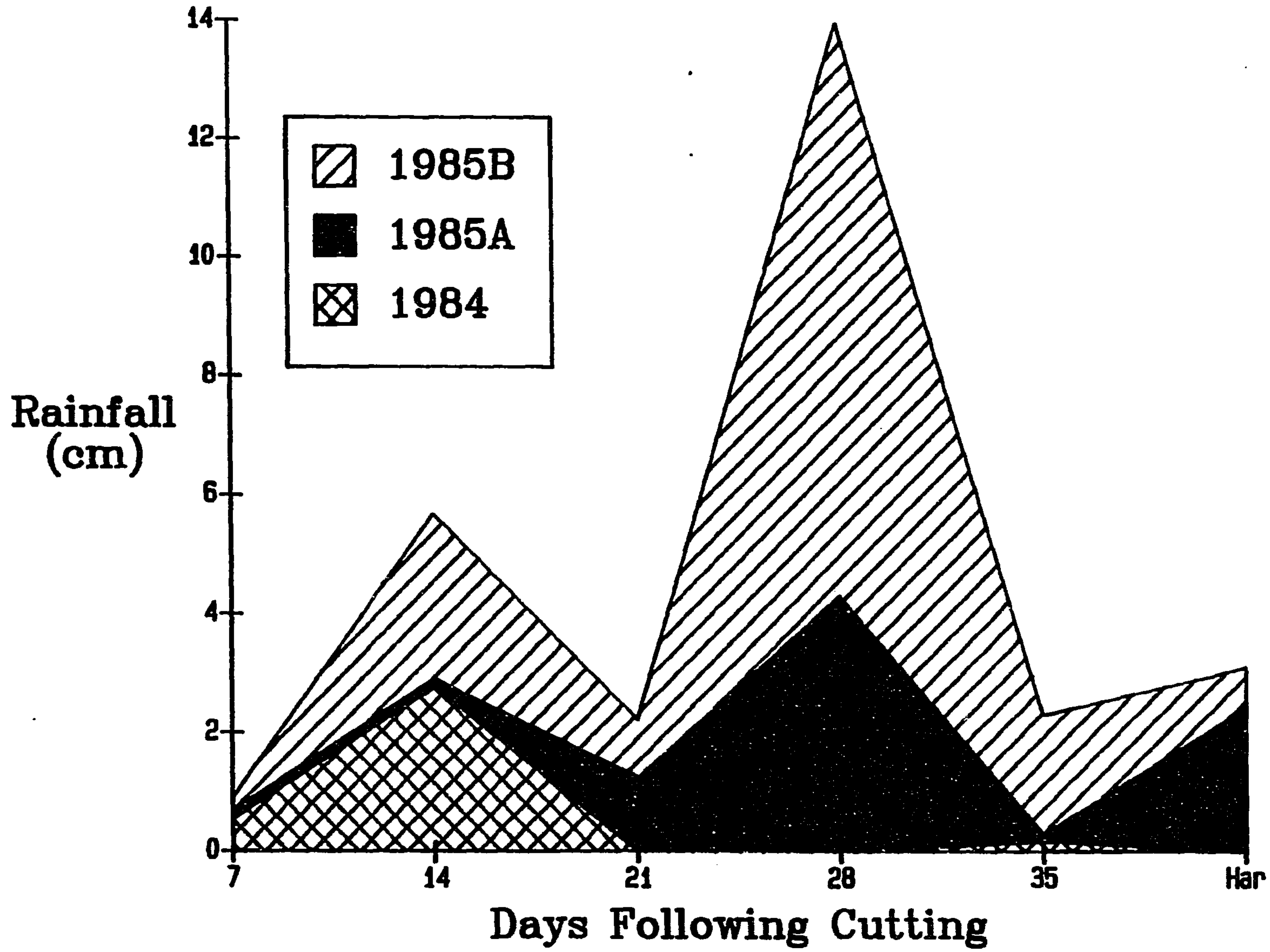
RESULTS AND DISCUSSION

A range of moisture conditions were experienced over the three field trials (Fig. 1.1). For the 1984 field trial, there was a net moisture deficit of 9.77 cm when compared to 30 year averages, with most of the deficit experienced in the final 28 days of growth. There was also a rainfall deficit in the 1985A study, although the degree of difference was considerably less (5.41 cm) and the distribution was more uniform. There was a surplus of moisture during the 1985B study when compared to 30-year averages. Much of the 3.84-cm surplus was the result of heavy rains during the fourth week of regrowth. The differences in rainfall patterns among the three trials resulted in significant differences among trials for many growth parameters. However, there were few trial by treatment interactions so the results of treatment comparisons will be discussed as averages over three trials.

Stem Initiation and Growth Characteristics

Final stem mass is a function of both stem density and individual stem characteristics during the period of regrowth. There were no significant reductions in the number of stems per m^2 observed at any sample period (Fig. 1.2). The initiation of new stem growth, therefore, was largely unaltered by the feeding mechanism of the PLH. By contrast, chewing insects, such as the alfalfa weevil, *Hypera postica* Ghllenhal), or the variegated cutworm, *Peridroma saucia* (Hubner), will often reduce

Figure 1.1. Rainfall patterns during the three field trials. Ames, IA


1985B
1985A
1984
Rainfall (cm)
0
2
4
6
8
10
12
14
7
14
21
28
35
Har
Days Following Cutting

the number of stems per area by consuming new growth soon after initiation (Buntin 1984). In the present study, stem density peaked ca. 14 days following first harvest and began to decline with the increased competition of additional growth. The fact that stem density differences were not seen between infested and uninfested plots suggests that injury is imposed on the plant after stem initiation and requires time to develop.

Although stem density is unaltered, PLH feeding does have a dramatic effect on the growth and development of the stem component. The most visible effect to this component is stem height (Fig. 1.3). Here, the reduction is very significant (P=0.01) for all infested plots vs. the check after 14 days of regrowth when infested early. For plants infested late, only 7 days of feeding are required to demonstrate a significant reduction in stem height. In most instances the effect appeared to be insensitive to PLH density. The implications of reduced stem height are manifold. First, the reduced stem component will translate to an overall reduced biomass if the leaf component does not compensate for the losses. Second, the reduced stem component will likely act to boost the overall quality of the forage per unit of mass because stem tissue is typically less available to ruminant digestion than leaf tissue (Mowat et al. 1965). Third, the reduced stem height may provide less opportunity for the leaves to compete for photosynthetically active radiation (PAR), and weed encroachment may occur.

Observations of reduced stem height resulting from PLH feeding have

Figure 1.2. Effect of various infestation periods and densities of potato leafhopper on alfalfa stem density averaged over three field trials. Ames, IA

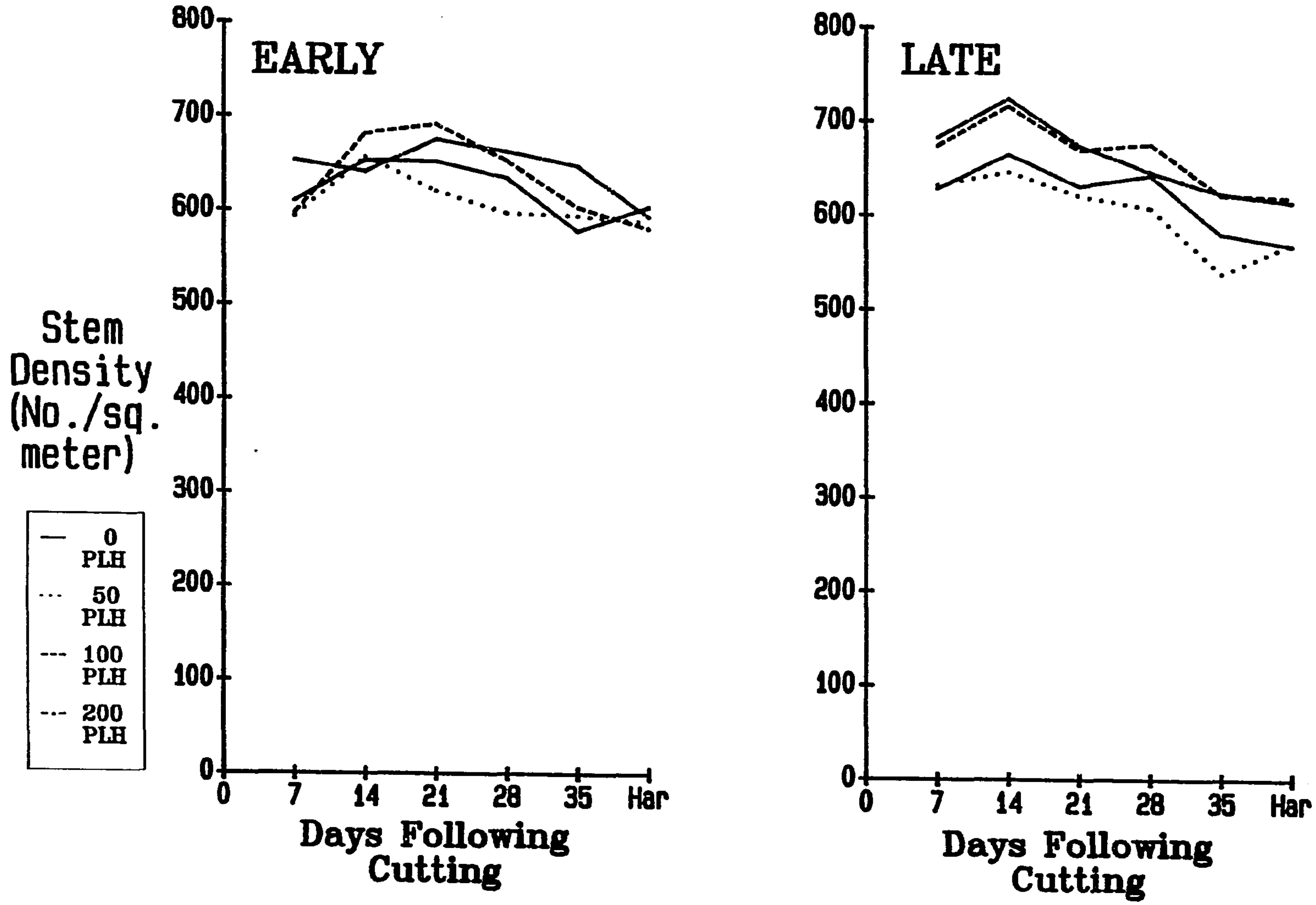
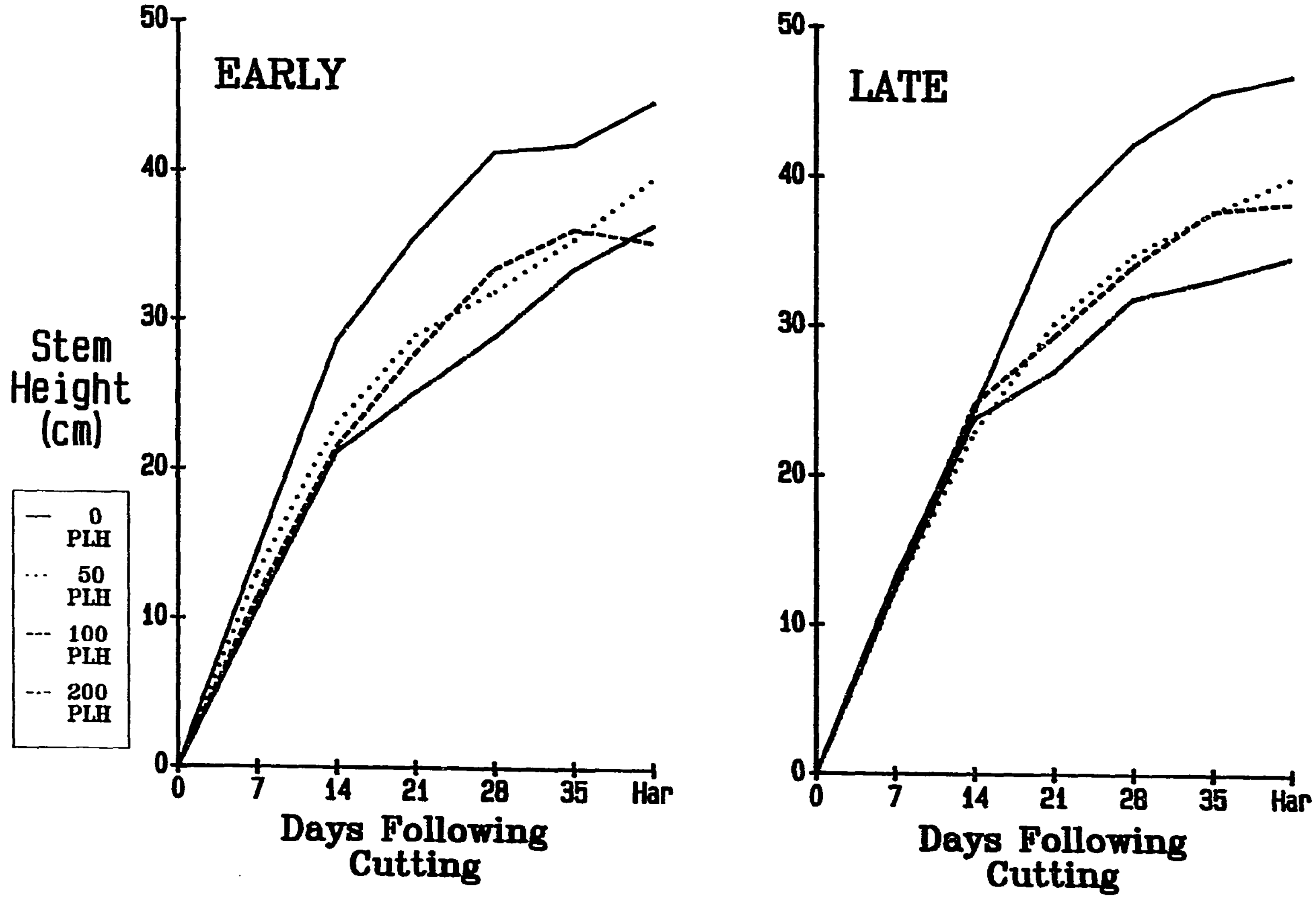

Stem Density (No./sq. meter)
EARLY
LATE
800
700
600
500
400
300
200
100
0
0 7 14 21 28 35 Har
Days Following Cutting
0 PLH
50 PLH
100 PLH
200 PLH

Figure 1.3. Effect of various infestation periods and densities of potato leafhopper on alfalfa stem height averaged over three field trials. Ames, IA


EARLY
LATE
Stem Height (cm)
50
40
30
20
10
0
0
7
14
21
28
35
Har
Days Following Cutting
0 PLH
50 PLH
100 PLH
200 PLH

been made previously (Faris et al. 1981; Smith and Ellis 1983). Further analysis of the mechanisms for stem growth, however, may provide evidence to identify the specific plant response. Data for two contributing factors to stem height, the number of mainstem nodes and the internodal distance, are presented in Table 1.1. Significant differences existed for each of these plant parameters. Reductions in the number of mainstem nodes parallels the reductions in stem height described previously. The greatest differences for the early infested plots were between the untreated plots and the low density plots. For the late infestation, higher densities were necessary to significantly reduce the number of mainstem nodes. Reductions in nodes were less dramatic by the final harvest period, which was after all plots had reached 1/10 bloom. The internodal distance was also reduced and added to stem height reductions. Here, the most significant differences were seen with infested vs. uninfested comparisons (i.e., A: 0 vs. 50-200 and B: 0 vs. 50-200). By final harvest the late infested plots were still experiencing shorter internodal distances.

The stem component represents a significant portion of the final biomass yield for the crop. Since the stem is not physically consumed with PLH feeding, and since the leaf component is the visible obvious site of feeding, further investigation into the effect of PLH injury to this plant component is necessary.

Table 1.1. Effect of various infestation periods and densities of potato leafhopper (PLH) on the number of mainstem nodes and internodal distance (cm) of alfalfa at three sample periods and over three field trials. Ames, IA

Infest Period	PLH Density	Number of Mainstem Nodes			Internodal Distance (cm)		
		14	28	HAR	14	28	HAR
A	0	6.59	9.63	11.12	4.42	4.36	4.10
	50	5.72	8.42	10.35	4.20	3.93	3.83
	100	5.54	8.65	9.18	4.09	3.96	3.88
	200	5.61	8.14	8.93	3.97	3.71	4.03
B	0	6.26	9.42	9.94	4.02	4.54	6.81
	50	6.31	9.00	9.79	3.73	4.03	4.10
	100	6.54	8.69	9.51	3.89	4.08	4.07
	200	6.14	8.18	9.34	4.02	4.07	3.76
Contrasts:[a]							
A: 0 vs 50-200		**	**	**	*	**	ns
A: 0-100 vs 200		ns	*	**	*	ns	ns
A: 0 vs 50		**	**	ns	ns	ns	ns
B: 0 vs 50-200		ns	*	ns	ns	**	**
B: 0-100 vs 200		ns	*	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	*	*
A vs B: 50-200		**	ns	ns	*	ns	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

Leaf Production and Expansion Characteristics

The leaf component of alfalfa exhibits the chlorotic symptoms of "hopperburn". The specific nature of the injury to the leaf and its effect on the physiological development of the crop are largely unknown. One possible reason for this lies in the failure of previous research to characterize the effect of PLH-induced injury on the leaf component. Although the dramatic stem height reductions are often considered the primary response of the plant to PLH-induced stress, the leaf component mediates stem growth via photosynthesis.

Paramount to evaluating the effect on the leaf component is the determination of plant and crop leaf area. Conventional techniques for measuring leaf area, however, are not sensitive enough to distinguish the injured portion of the leaf from the healthy portion. Therefore, to avoid overestimating leaf chlorosis, the measurements for leaf area parameters were adjusted to consider only the healthy leaf tissue. The adjustment consisted of measuring the amount of injury to individual leaves throughout the season with a video contrast-sensitive leaf area meter and calculating the proportion of leaf area injured. Hence, the total adjusted leaf area for the canopy consisted of the leaf area of healthy leaves plus the healthy portion of the injured leaves. Using this technique, the mean proportion of chlorosis for an injured leaf was determined to be 0.32 (n = 57; SD = 0.09).

To document the response of the alfalfa leaf component to PLH-feeding, it was necessary to establish a gradation of visible symptoms in the field trials. Based on values for adjusted damaged leaf area per m^2

(Fig. 1.4), the infestation techniques used in these experiments were successful. Damaged leaf area (cm^2) was higher for the early infestation and peaked at 35 days following infestation. The damaged leaf area for the late infested plots was continuing to increase at the time of harvest, and was also seen to be a gradual response.

The specific characteristics of individual leaves were largely unaltered (Table 1.2). The adjusted leaf area per leaf was uniform among treatments and stable over most sample dates. The average leaf weight per leaf was less uniform. At 28 days after infestation, the average leaf weight per leaf for the early infested plots was significantly lower than the check plots. This reduction carried over to the early vs. late comparison. The adjusted leaf area ratio (cm^2/gm of forage) and the adjusted specific leaf area (cm^2/mg of leaf) also was largely unaffected throughout the experiment (Table 1.3). The higher levels of rainfall in the 1985B trial allowed for higher ratios for these values. The relative stability among treatments, however, was generally unaffected (except for the B: 0-100 vs 200 comparison).

The measurement of leaf area index (LAI) provides an indication of the ratio of leaf area to land area. Adjustment of the LAI to consider only the non-chlorotic leaf area, referred to as the effective leaf area index (ELAI), will provide an estimate of LAI for this non-destructive form of injury. Indeed, when LAI values are adjusted to ELAI, there are significant differences between the infested and uninfested plots for both early and late infestations (Fig. 1.5). When alfalfa was infested

Figure 1.4. Effect of various infestation periods and densities of potato leafhopper on the adjusted damaged leaf area of alfalfa per m^2 of land (cm^2) averaged over three field trials. Ames, IA

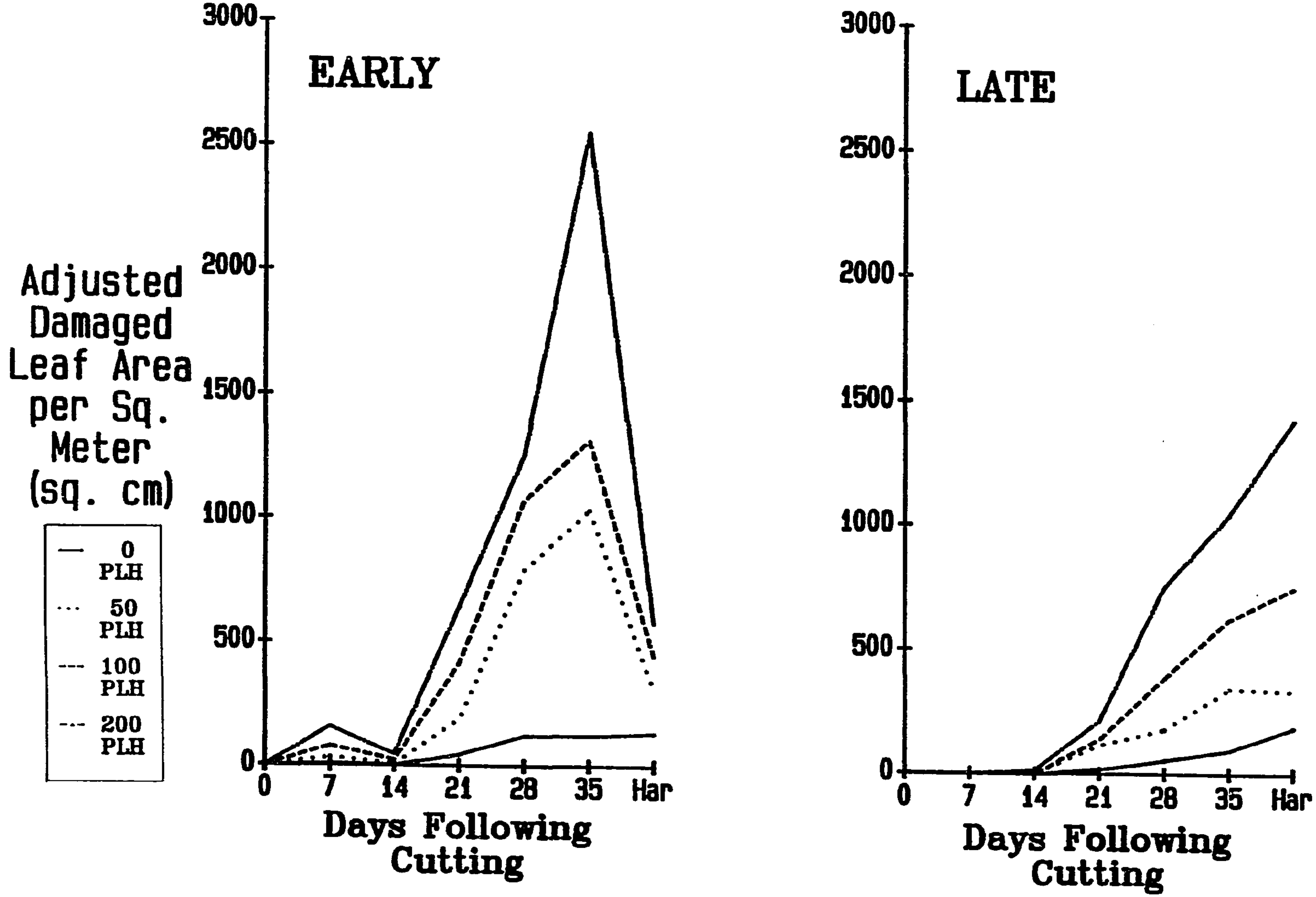

Adjusted Damaged Leaf Area per Sq. Meter (sq. cm)
0 PLH
50 PLH
100 PLH
200 PLH
EARLY
LATE
3000
2500
2000
1500
1000
500
0
0
7
14
21
28
35
Har
Days Following Cutting

Table 1.2. Effect of various infestation periods and densities of potato leafhopper (PLH) on the adjusted average leaf area per leaf (cm^2) and average leaf weight per leaf (mg) of alfalfa at three sample dates over three field trials. Ames, IA

Infest Period	PLH Density	Adjusted Ave. Leaf Area/Leaf (cm^2) 14	28	HAR	Ave. Leaf Weight/Leaf (mg) 14	28	HAR
A	0	0.71	0.60	0.39	3.28	3.23	2.24
	50	0.69	0.58	0.37	3.16	3.53	2.12
	100	0.69	0.62	0.35	3.10	3.69	2.21
	200	0.66	0.61	0.37	2.89	3.71	2.12
B	0	0.71	0.64	0.41	3.35	3.21	2.30
	50	0.63	0.66	0.38	3.11	2.97	2.19
	100	0.61	0.63	0.37	3.17	3.31	2.56
	200	0.66	0.61	0.37	3.13	3.37	2.44
Contrasts:[a]							
A: 0 vs 50-200		ns	ns	ns	ns	**	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns
A vs B: 50-200		ns	ns	ns	ns	**	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

Table 1.3. Effect of various infestation periods and densities of potato leafhopper (PLH) on the adjusted leaf area ratio (cm^2/gm total forage) and adjusted specific leaf area (cm^2/mg of leaf) of alfalfa at harvest for each field trial and an overall mean. Ames, IA

Infest Period	PLH Density	Adjusted Leaf Area Ratio (cm^2/gm)				Adjusted Specific Leaf Area (cm^2/mg)			
		1984	1985A	1985B	Overall	1984	1985A	1985B	Overall
A	0	52.37	59.65	87.49	66.50	0.12	0.13	0.24	0.17
	50	54.78	74.40	79.69	69.63	0.13	0.16	0.23	0.17
	100	49.98	67.53	76.13	64.55	0.12	0.14	0.21	0.16
	200	59.06	73.74	81.33	71.37	0.15	0.15	0.23	0.17
B	0	65.24	56.03	80.63	67.30	0.15	0.14	0.23	0.17
	50	59.17	63.85	97.88	73.63	0.14	0.14	0.25	0.18
	100	54.44	55.43	87.31	65.73	0.14	0.12	0.23	0.16
	200	66.71	55.93	65.32	62.66	0.15	0.12	0.18	0.15
Contrasts:[a]									
A: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	*	ns	ns	ns	*	*
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		ns	*	ns	ns	ns	*	ns	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (NS).

immediately after cutting, the ratio of non-chlorotic leaf tissue to ground area was lower for the infested plots by the first sample date following infestation. Similarly, the ELAI was lower within seven days when infested late. By harvest, the ELAI values for early and late infested plots were similar. Although the gradation of PLH density was uniform, the plant response in terms of ELAI appeared to be more discrete and could be viewed as infested or non-infested.

Growth Analysis and Nutrient Partitioning

The specific crop response to PLH feeding is dependent on the temporal occurrence of the stress and the physiological state of the crop. Moreover, final crop yield is the cumulative result of the various growth patterns throughout the season. The final yield, therefore, represents an end point subject to the interactions among the plant, the insect, and other stressors. Biomass yield, which represents the combined stem and leaf production, is presented in Fig. 1.6. Biomass production was unresponsive to PLH density beyond the lowest density, with all infested plots producing less yield. Moreover, both the early and late infested plots demonstrated biomass reductions within seven days after infestation. However, the rate of decrease was higher for late infested plots so that biomass loss was similar by harvest.

Differences in biomass yield can be attributed to specific reductions in growth rates at different times within the regrowth period. Average crop growth rates (CGR) were lower for all infested plots during

Figure 1.5. Effect of various infestation periods and densities of potato leafhopper on the effective leaf area index of alfalfa averaged over three field trials. Ames, IA

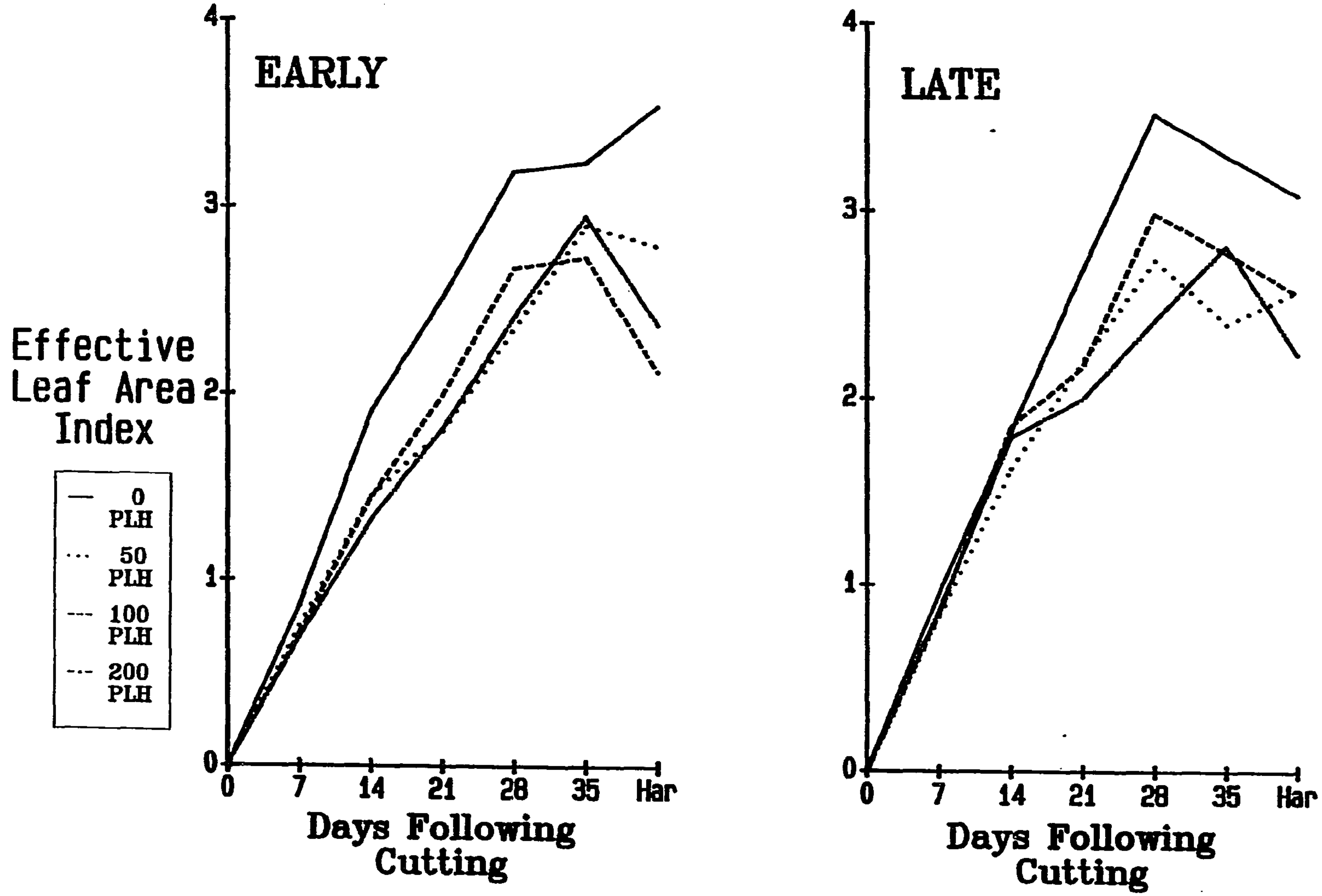

EARLY
LATE
Effective Leaf Area Index
0 PLH
50 PLH
100 PLH
200 PLH
0
1
2
3
4
0
7
14
21
28
35
Har
Days Following Cutting

Figure 1.6. Effect of various infestation periods and densities of potato leafhopper on the total biomass (kg/ha) of alfalfa averaged over three field trials. Ames, IA

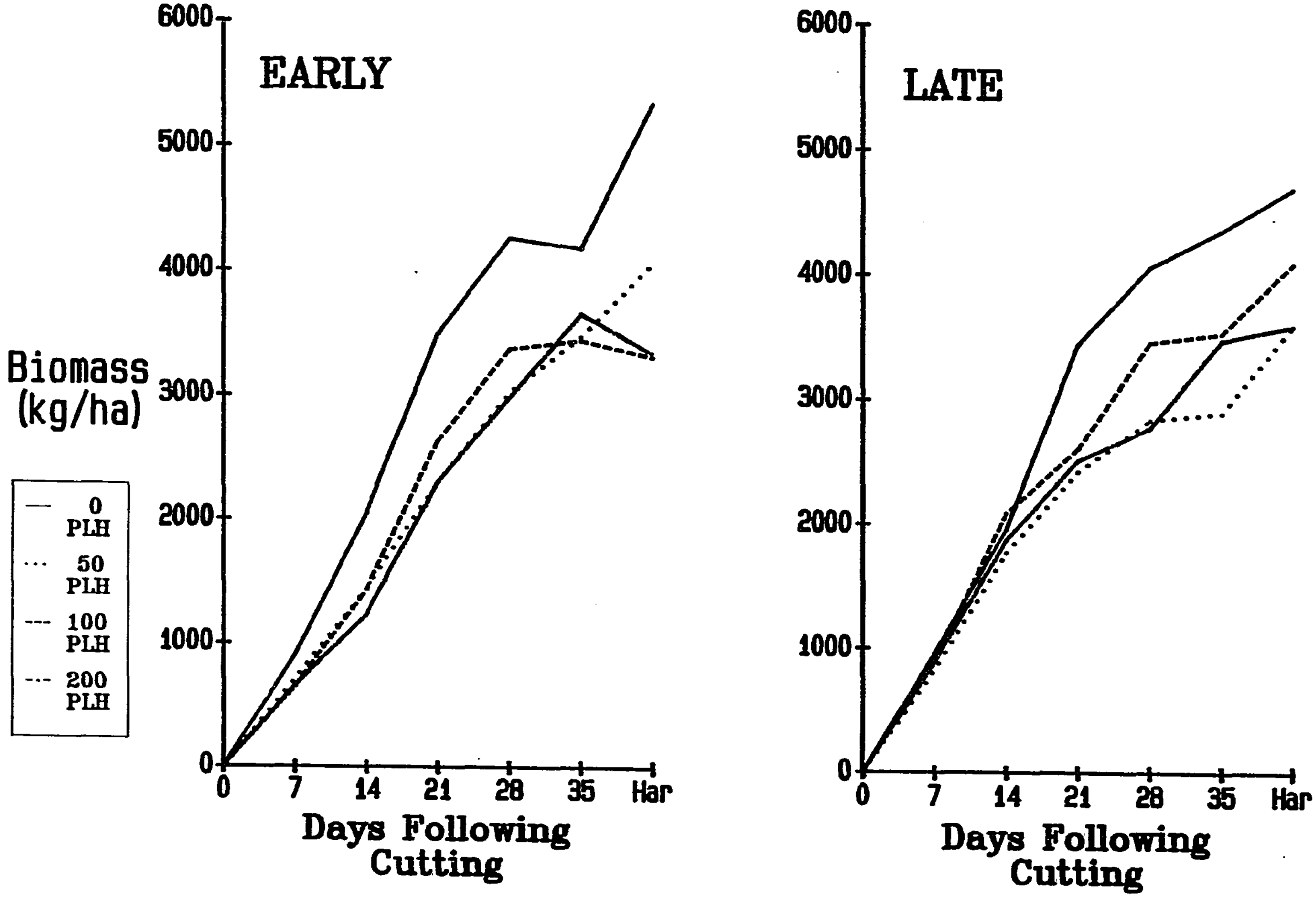

EARLY
LATE
Biomass (kg/ha)
6000
5000
4000
3000
2000
1000
0
0
7
14
21
28
35
Har
Days Following Cutting
0 PLH
50 PLH
100 PLH
200 PLH

Table 1.4. Effect of various infestation periods and densities of potato leafhopper (PLH) on the crop growth rate (gm/m^2 of land/day) of alfalfa at two sample dates for each of three field trials. Ames, IA

Infest Period	PLH Density	1984 7-14	1984 28-35	1985A 7-14	1985A 28-35	1985B 7-14	1985B 28-35	Mean 7-14	Mean 28-35
A	0	11.03	5.63	11.38	2.29	8.27	5.60	10.22	4.51
	50	8.11	17.86	4.96	2.11	4.86	17.07	5.97	12.35
	100	7.60	11.88	2.35	0.82	8.86	21.07	6.27	11.26
	200	6.95	18.46	2.75	0.00	3.83	30.16	4.51	16.21
B	0	18.04	0.00	3.21	7.48	7.53	8.04	9.60	5.18
	50	20.65	10.66	0.83	1.49	10.31	14.90	10.60	9.02
	100	19.38	16.57	5.41	13.11	7.69	2.40	10.83	10.69
	200	14.06	13.69	8.87	4.69	8.19	14.31	10.37	10.90
Contrasts:[a]									
A: 0 vs 50-200		ns	ns	*	ns	ns	ns	ns	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	*	ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		**	ns	ns	ns	*	ns	*	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (NS).

Table 1.5. Effect of various infestation periods and densities of potato leafhopper (PLH) on the stem growth rate (gm/m^2 of land/day) of alfalfa at two sample dates for each of three field trials. Ames, IA

		1984		1985A		1985B		Mean	
Infest Period	PLH Density	7-14	28-35	7-14	28-35	7-14	28-35	7-14	28-35
A	0	6.03	0.72	8.28	1.17	4.56	4.26	6.29	2.05
	50	3.70	7.12	3.81	1.67	2.30	12.89	3.27	7.23
	100	3.58	4.45	1.98	1.21	4.79	17.23	3.45	7.63
	200	2.80	8.01	2.81	0.00	1.93	21.68	2.51	9.90
B	0	9.42	0.00	2.55	3.37	4.44	8.91	5.47	4.09
	50	10.56	3.71	0.50	0.00	5.99	11.15	5.69	4.95
	100	9.73	6.43	3.35	8.65	4.41	3.92	5.83	6.33
	200	6.45	3.51	6.16	4.11	4.45	8.35	5.69	5.32
Contrasts:[a]									
A: 0 vs 50-200		ns	ns	*	ns	ns	*	ns	*
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		**	ns	ns	ns	ns	*	*	ns

[a] F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (NS).

Table 1.6. Effect of various infestation periods and densities of potato leafhopper (PLH) on the leaf growth rate (gm/m^2 of land/day) of alfalfa at two sample dates for each of three field trials. Ames, IA

Infest Period	PLH Density	1984		1985A		1985B		Mean	
		7-14	28-35	7-14	28-35	7-14	28-35	7-14	28-35
A	0	5.07	8.42	3.27	1.12	3.70	1.47	4.01	3.67
	50	4.65	11.60	1.53	0.45	2.98	5.12	3.05	5.72
	100	4.02	8.14	0.41	0.00	4.06	3.92	2.83	4.02
	200	4.15	10.83	0.69	0.00	1.98	8.48	2.28	6.44
B	0	8.62	0.53	0.67	4.12	3.09	1.19	4.12	1.95
	50	10.09	6.95	0.33	1.53	4.31	4.54	4.91	4.34
	100	9.65	10.14	2.06	5.08	3.27	0.00	4.99	5.07
	200	7.62	11.65	2.97	1.20	3.74	5.96	4.77	6.27
Contrasts:[a]									
A: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	*	ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		**	ns	ns	ns	ns	ns	*	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (NS).

the early stages of regrowth (Table 1.4). In contrast, however, the CGR difference was reversed during the later portions of development. This response was consistent for all the infested plots (except the 1985A study) and suggests that the crop was in a compensitory mode of development.

Although the plants were under considerable PLH stress throughout the growing season, the specific reaction to that stress was clearly different. The stem growth rate (SGR) followed closely the response of CGR during the early and late phases of regrowth (Table 1.5). The differences were most dramatic during the early infested plots but were also present in the late infested plots. Annual variation was significant, but the treatments were still discernible. Values for leaf growth rate (LGR) were more consistent with regard to changes in seasonal development (Table 1.6). The decreased growth of infested plots were maintained, albeit at a lower level. Similarly, the magnitude of the compensation phase later in the season for injured plants was reduced. These differences suggest that the majority of the overall differences in CGR and biomass yield are accounted for in the stem component. Moreover, the data suggests that early losses will be partially compensated for later in the season.

Further evidence of the compensatory response of alfalfa to PLH-induced stress can be seen with differences in the net assimilation rate (NAR, Table 1.7). The values for this growth parameter suggest that the crop is hindered in development by PLH feeding initially, but will

Table 1.7. Effect of various infestation periods and densities of potato leafhopper (PLH) on the net assimilation rate (gm/cm^2 of leaf/day) of alfalfa at two sample dates for each of three field trials. Ames, IA

		1984		1985A		1985B		Mean	
Infest Period	PLH Density	7-14	28-35	7-14	28-35	7-14	28-35	7-14	28-35
A	0	1.18	0.16	0.81	0.10	0.33	0.16	0.78	0.14
	50	0.92	0.73	0.38	0.11	0.37	0.58	0.56	0.87
	100	1.00	0.47	0.20	0.04	0.58	0.70	0.59	0.40
	200	0.96	0.84	0.24	0.00	0.28	0.92	0.49	0.59
B	0	1.58	0.00	0.21	0.25	0.36	0.27	0.72	0.17
	50	1.95	0.35	0.06	0.09	0.64	0.68	0.88	0.37
	100	1.54	0.62	0.38	0.51	0.39	0.10	0.77	0.41
	200	1.24	0.57	0.60	0.20	0.41	0.52	0.75	0.43
Contrasts:[a]									
A: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		**	ns	ns	ns	ns	ns	ns	ns

[a]*F* values for contrasts determined to be significant (*, *P*=0.05), highly significant (**, *P*=.01), or not significant (NS).

compensate as development progresses. The net result, therefore, will be a delay in the development of the crop.

Conclusions and Implications

Alfalfa stressed by PLH feeding will develop atypically. The nature of the deviation varies with the time of infestation and which plant component is considered (i.e., stem or leaf). Stems are reduced in SGR and this translates to a reduced overall height and mass. Leaves are reduced in their ELAI but maintain their individual characteristics of area and mass per leaflet. Although analyzed separately, the two plant components are dependent upon each other. Reductions in leaf productivity, measured as a reduced effective leaf area and NAR, result in a disproportionate amount of photosynthetic energy necessary for maintenance, rather than growth. This adjustment in partitioning is expressed as reduced stem production and an overall reduction in the rate of development (CGR). As unstressed plants reach a natural decline in growth with the reproduction phases, the stressed plants are actively compensating for early reductions.

The recommendation to cut early has often been proposed to manage insect-induced losses late in the regrowth period (Shoemaker and Onstad 1983). Their analysis includes simulations for crop and insect development and annual yields to determine optimal strategies based on total monetary incomes. Although this approach may be appropriate under some circumstances, results of the current field studies suggest that the early harvest strategy may negate any compensatory response of the crop and hence eliminate the potential for recovering early losses. The final decision on whether or not to cut early should be based on the production objectives of the grower based on the whole-farm management plan.

PART II. EFFECT OF POTATO LEAFHOPPER FEEDING ON DIGESTIBILITY, CRUDE PROTEIN, AND CELL-WALL CONCENTRATION OF ALFALFA

ABSTRACT

Three field trials were conducted in 1984 and 1985 to determine the consequence of potato leafhopper (PLH), Empoasca fabae (Harris), feeding on the chemical composition and nutritional quality of alfalfa and the separate stem and leaf components. A factorial arrangement of four densities of PLH adults (0, 50, 100, 200/m^2) and two infestation periods (1- and 14-days after first harvest) were arranged in a randomized complete-block design with four replications. A split-plot in time was superimposed with subplots representing weekly plant samples for assays of digestibility, cell-wall concentration, and crude protein. Data were subjected to an analysis of variance, followed by orthogonal comparisons of treatments.

Measurements for in-vitro digestibility were not significantly different among the plots. The stem component was actually enhanced in digestibility by severe PLH feeding, but the leaf component was slightly less digestible. Similarly, the overall cell-wall concentration was largely unaffected by PLH-induced injury at harvest. Levels of crude protein were significantly altered by PLH feeding. Leaf proteins were reduced in most infested plots, but stem proteins were maintained or even enhanced with increasing levels of injury. Comparisons of chlorotic versus non-chlorotic leaves suggest that the visible symptoms of PLH feeding may not necessarily indicate differences in the chemical composition of the forage. Calculated measures for animal growth and utilization based on the chemical composition (digestible dry matter

intake, relative feed value, and digestible energy) are presented for production reference.

Results of this study indicate that pest management programs for PLH should be based on biomass or nutrient yield per hectare reductions, rather than quality reductions per se.

INTRODUCTION

Polyphagous insect pests have often been implicated as causing severe yield and quality losses to alfalfa, Medicago sativa L. The potato leafhopper (PLH), Empoasca fabae (Harris), has been identified as one of the most severe alfalfa pests in the North Central United States (Smith and Ellis 1983) and is frequently cited as limiting the production of this primary forage species (Hower and Muka 1975; Faris et al. 1981). The PLH feeds by inserting its piercing-sucking mouthparts into the phloem elements and extracting plant juices. Injury to the plant, then, is believed to be the destruction and clogging of phloem tissue resulting from repeated insertion of the stylet. The visible symptoms of PLH feeding are referred to as "hopperburn", and can be seen as a V-shaped chlorosis originating from the apex of the leaf.

Biomass reductions associated with PLH feeding have been documented on many occasions (e.g., Kouskolekas and Decker 1968). However, the impact on the chemical composition of alfalfa subjected to PLH feeding is poorly defined. A characterization of "alfalfa quality" is difficult because of the variety of applications for which the crop can be utilized (e.g., dairy vs. sheep production). Nevertheless, certain characteristics of any forage are clearly associated with increased animal utilization and production. Specifically, the proportion of the feed which is readily digestible provides a simple means for comparing the availability of ingested nutrients. In addition, potential animal intake (negatively correlated with the cell-wall concentration) is another factor affecting final animal utilization. Intake is an aspect of forage quality, the species of the consumer, the animal's physiological status, the animal's energy demand, and the animal's individual preference (Van Soest 1982). Although intake and digestibility are frequently assumed to be related, intake is dependent on structural volume (i.e., cell-wall), and digestibility is dependent upon both cell-wall and its degree of lignification. Other characteristics associated with a high quality forage, such as crude protein levels, also impact the usefulness of the feed. In most situations, however, metabolic requirements are not limiting, because other factors of feed quality impose a lower level of feed intake.

Relatively few damage assessment studies have been conducted to investigate the potential for chemical composition alterations from PLH feeding. In addition, the exact site of the alteration (e.g., stem vs. leaf) has not been elucidated. The objective of this study was to provide information on the consequence of PLH feeding on both the stem and leaf component. In addition, healthy leaves, visibly injured leaves, and leaves subject to feeding but not visible injured were analyzed separately to determine possible mechanisms of injury. Finally, these parameters will be used to calculate quality indices of production for comparison to other feeds. Information from this study will serve to direct future pest management programs designed to protect alfalfa from PLH-induced injury.

MATERIALS AND METHODS

A stand of 'Blazar' alfalfa, Medicago sativa L., was seeded on 25 April 1984 in a 2.3-ha field near Ames, Iowa. All plots were drill-planted in 17.5-cm rows at the rate of 15.7-kg of seed per hectare on a Webster silty clay loam (fine loamy, mixed, mesic Typic Haplaquoll). An application of Eptam® (20 April 1984) was made prior to planting, and the field was topdressed with 135 kg/ha of P and 225 kg/ha of K prior to growth each Spring. Daily temperature and rainfall information were obtained from National Oceanic and Atmospheric Administration weather station 0200-05 (ca. 12-km west of the plots), and management practices typical of alfalfa production in central Iowa were followed. One field trial was conducted in 1984, and two field trials were conducted in 1985.

During 1984, all plots remained undisturbed during the first regrowth period and were cut to a height of 6.4 cm on 14 July 1984. Immediately following harvest, all plant material was removed and the plot area was raked to remove residual debris and stubble. Thirty-two experimental units, each consisting of a 1-m x 2-m area were established according to a randomized complete-block design. Within each block a 2 x 4 factorial arrangement of PLH density (0, 50, 100, and 200/m^2) and infestation period (1 day following harvest or 14 days following harvest) was instituted. Immediately following first harvest, a Saran® mesh cage (1-m x 2-m x 1-m tall) was installed over each plot to be infested early. Adult PLH were collected from an adjacent field of glabrous soybean (isoline of 'Clark') with a D-Vac® vacuum insect net and returned to the laboratory for separation. Adults were aspirated in quantities of 50 into test tubes and the necessary number of test tubes were carefully discharged into the caged plots (e.g., 200 PLH/m^2 required 8 test tubes). Plots remained covered for 14 days to allow for oviposition. After the less mobile nymphal populations were established, the cages were relocated to the late infested plots and the PLH collection and infestation procedure was repeated. The 14-day caging was necessary to maximize oviposition and minimize the effects of shading on the plots. The plot and surrounding areas were monitored frequently to insure that transitory feeding from native PLH populations did not occur. In addition, the adjacent glabrous soybean planting is believed to have attracted native populations away from the plot areas.

In the 1985 field studies all plots were established and maintained as in 1984, except at different areas within the 2.3-ha field. The first trial (1985A) received an early infestation on 2 July, and the second trial received an early infestation on 31 July.

In each of the three trials, a split-plot in time was superimposed, with subplots representing destructive plant samples taken weekly from one-half of the plot area (1-m x 1-m). The remaining half of the plot area was utilized for weekly stem density counts and for final yield measurements. A stem sample of 15 stems per plot was collected to characterize the physical growth and development of the plants. Measurements of stem and leaf weights were recorded to calculate leaf-to-stem ratios and for separate quality analysis. A second stem sample, consisting of a 25-stem bouquet, was also collected and dried for quality assay.

The plant samples collected for quality determinations were ground with a Wiley mill through a 1-mm seive and placed in a airtight glass jar. Each sample was subjected to an array of assays to determine the chemical composition of the forage. Specifically, all samples were subjected to an in-vitro digestible dry matter (IVDDM) analysis to determine percent digestibility (Tilley and Terry 1963), a neutral-detergent fiber analysis to determine the cell-wall concentration (Van Soest and Wine 1967), and a micro-Kjeldahl analysis to determine percent nitrogen and crude protein (Bremner and Mulvaney 1982). In addition to the intact forage, individual analyses were conducted on the leaf and stem components of the samples.

Statistical Analyses

All measured and calculated values for plant growth and quality were analyzed by year and sample date with an analysis-of-variance (ANOVA) procedure and a least-significant-difference (LSD) determination (means for this analysis are listed in Appendix C). The complete variable and program listing is in Appendix A, and the raw data are presented in Appendix B. An ANOVA over all years by sample date (days 7, 14, 21, 28, and 35) and at second harvest (2-Har) was also conducted, with whole-plot differences determined by orthogonal comparisons. These contrasts were believed to be the most efficient means of determining class differences (e.g., early vs. late infestation) among whole-plot combinations. The specific contrasts used in the orthogonal comparisons (labelled as infestation period: PLH densities) were: A: 0 versus 50-200, A: 0-100 versus 200, A: 0 versus 50, B: 0 versus 50-200, B: 0-100 versus 200, B: 0 versus 50, A versus B: 50-200. These comparisons were chosen based on visual observations of growth parameters for each plot and on *a priori* hypotheses.

RESULTS AND DISCUSSION

Rainfall patterns were variable over the period of the experiment (Fig. 2.1). Compared to 30-yr averages, there was a deficit of rainfall amounting to 9.77 and 5.41 cm in the 1984 and 1985A trials, respectively. In contrast, there was a 3.84-cm surplus of rainfall in the 1985B trial compared to 30-yr averages. The 1984 study received the majority of its moisture during the first 14 days of regrowth, but the 1985A trial received little of its total moisture during this period. Much of the moisture surplus for the 1985B trial resulted from heavy rains during the fourth week of regrowth. Although these contrasting rainfall patterns resulted in annual differences for growth, there were few treatment by trial interactions. Therefore, treatment comparisons are presented as averages over three trials.

Forage Quality Determinations

The distribution of mass between plant parts is presented as a ratio of leaf tissue to stem tissue (Fig. 2.2). PLH-induced injury significantly reduced the stem component relative to the leaf component. Reduced rates of nodal development and stem elongation have been associated with PLH feeding (Kouskolekas and Decker 1968) and likely altered the leaf:stem ratio. In the present study, significant differences were observed within seven days of infestation for both the early and late infested plots. Inasmuch as stems and leaves contribute to the overall quality of

Figure 2.1. Rainfall patterns during the three field trials. Ames, IA

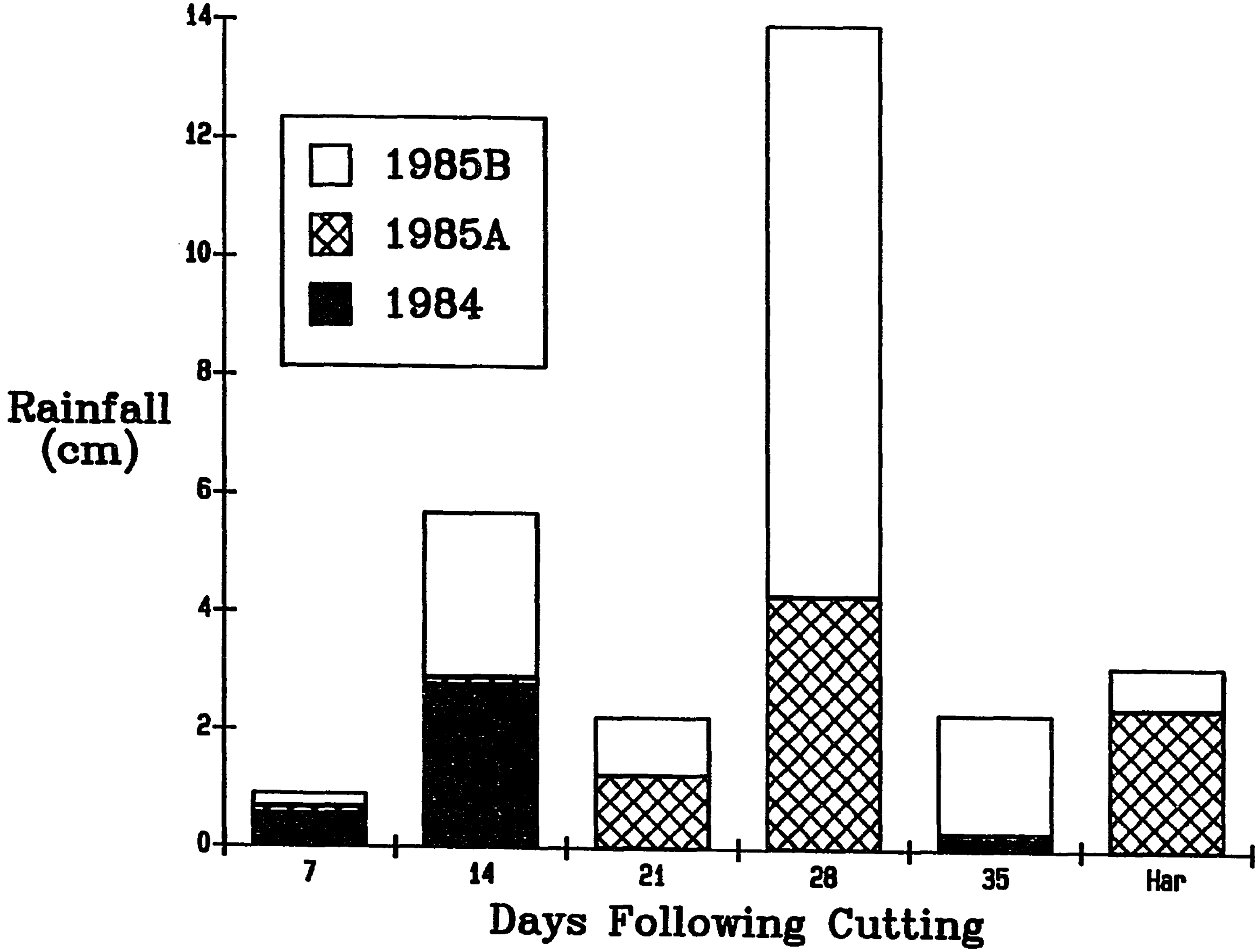
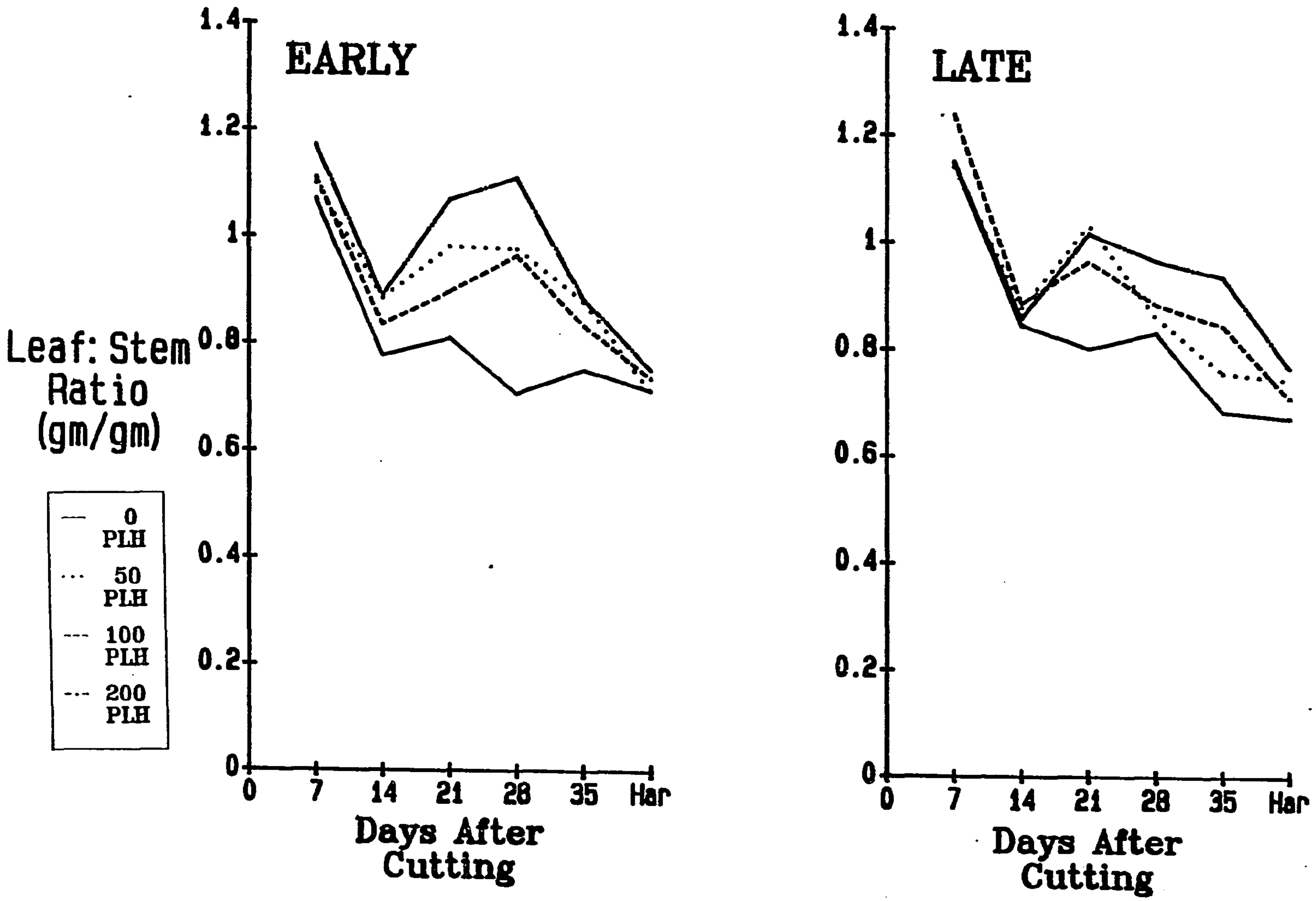

1985B
1985A
1984
Rainfall (cm)
0
2
4
6
8
10
12
14
7
14
21
28
35
Har
Days Following Cutting

Figure 2.2. Effect of various infestation periods and densities of potato leafhopper on the leaf:stem biomass ratio of alfalfa averaged over three field trials. Ames, IA


EARLY
LATE
Leaf: Stem Ratio (gm/gm)
0 PLH
50 PLH
100 PLH
200 PLH
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
7
14
21
28
35
Har
Days After Cutting

the forage, both should be characterized to partition the contribution of the components.

Digestibility relates to the proportion of a plant tissue which is susceptible to rumen or gastric breakdown and utilization by the animal. Table 2.1 presents data on forage and component digestibility at three sample intervals. The overall digestibility of the alfalfa stems remained largely unchanged throughout the season, indicating that PLH feeding does not reduce the availability of the alfalfa once it is ingested. The stem component also was largely unaffected in digestibility by PLH feeding. The only instances where digestibility was significantly altered was in the early infested plots at 28-days post infestation and in the high PLH density plots infested late. In each of these instances the digestibility was actually increased with additional PLH-induced injury. The reduction in the stem component compared to the leaf component may have resulted, by default, in a more digestible plant. The leaf component, viewed separately, also was largely unaffected by PLH feeding. The most significant exception to this occurred in the late infested plots, where leaves subjected to intense PLH feeding were significantly more digestible than uninfested leaves.

Measurements of cell-wall concentration, which are generally negatively correlated with intake of a feed, are presented in Table 2.2. As with digestibility, there were few differences in cell-wall concentrations among the plots. Cell-wall concentration of the plants generally increased with PLH feeding, but most differences were too small

Table 2.1. Effect of various infestation periods and densities of potato leafhopper (PLH) on the forage, stem, and leaf *in-vitro* digestibility (IVDDM, %) of alfalfa at three sample periods and over three field trials. Ames, IA

Infest Period	PLH Density	Forage IVDDM			Stem IVDDM			Leaf IVDDM		
		14	28	HAR	14	28	HAR	14	28	Har
A	0	73.78	73.02	66.14	73.69	62.50	56.34	81.81	77.25	74.36
	50	75.26	74.20	66.39	74.79	64.69	56.91	80.78	77.63	74.57
	100	74.05	71.54	66.43	75.44	65.83	55.43	80.01	78.31	72.55
	200	74.02	71.66	65.47	75.88	64.28	57.71	79.98	78.66	74.15
B	0	73.63	72.62	66.00	74.81	64.90	57.23	81.76	76.03	72.53
	50	74.95	71.23	67.73	74.91	64.70	55.80	80.56	77.54	73.28
	100	76.20	72.20	65.93	73.70	65.47	56.73	80.58	79.05	72.24
	200	73.62	72.72	66.93	74.73	64.96	58.88	82.04	78.48	75.01
Contrasts:[a]										
A: 0 vs 50-200		ns	ns	ns	ns	*	ns	ns	ns	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	**	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	**	ns	ns	**
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		ns	ns	ns	ns	ns	ns	ns	ns	ns

[a] *F* values for contrasts determined to be significant (*, *P*=0.05), highly significant (**, *P*=.01), or not significant (ns).

Table 2.2. Effect of various infestation periods and densities of potato leafhopper (PLH) on the forage, stem, and leaf cell wall concentration (%) of alfalfa at three sample periods and over three field trials. Ames, IA

		Forage Cell Wall			Stem Cell Wall			Leaf Cell Wall		
Infest Period	PLH Density	14	28	HAR	14	28	HAR	14	28	Har
A	0	53.31	54.67	59.51	51.54	61.75	63.65	36.39	43.12	43.52
	50	50.13	55.22	58.88	51.35	59.72	64.65	38.35	45.16	44.22
	100	53.50	58.33	59.02	55.22	60.45	66.08	39.66	47.07	46.06
	200	52.67	59.87	58.04	50.64	57.79	66.50	37.09	50.27	43.62
B	0	50.17	47.19	57.62	56.77	60.92	64.90	40.47	42.28	43.67
	50	51.43	54.35	58.94	55.94	57.04	65.27	35.55	44.38	41.69
	100	51.52	55.41	59.88	56.65	59.44	64.89	39.76	43.94	45.46
	200	51.27	56.79	58.87	57.89	56.84	65.02	38.31	48.84	43.93
Contrasts:[a]										
A: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	*	ns
A: 0-100 vs 200		ns	*	ns	ns	*	ns	ns	**	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	**	ns	ns	*	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	**	ns
B: 0 vs 50		ns	ns	ns	ns	**	ns	ns	ns	ns
A vs B: 50-200		ns	ns	ns	*	ns	ns	ns	ns	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

to be significant. Stems contained significantly lower concentrations of cell-wall in plots infested late and with 200 PLH per m^2. The differences were most significant at 28-days post infestation, and declined by harvest. In contrast, plots with heavy PLH feeding had leaves with greater cell-wall concentrations when compared to uninfested plots. The highest density plots for both infestation periods had leaves with a significantly higher cell-wall concentration 28-days into regrowth. The noted decrease in cell-wall concentration of stems was partially offset by the increase in the cell-wall concentration of leaves. Therefore, the net result was no change in the potential intake of the alfalfa.

Crude protein reductions have often been implicated as being the most severely reduced quality component from PLH feeding (Kindler et al. 1973). Measurements of crude protein for the forage samples conducted over the three field trials are presented in Table 2.3. A significant reduction was observed in the levels of crude protein for plants infested early. The stem component actually increased in protein levels with PLH feeding, but the increases were not maintained through harvest. Leaf proteins declined, however, throughout the regrowth period. Reductions were noted in the early and late infested plots and occurred at the lowest levels of PLH feeding. Although the leaf protein reductions are clearly reduced, their final levels may still be more than sufficient to meet the maintenance and growth requirements of the animal consumer. Indeed, the intake of available energy is most frequently cited as the

Table 2.3. Effect of various infestation periods and densities of potato leafhopper (PLH) on the forage, stem, and leaf protein (%) of alfalfa at three sample periods and over three field trials. Ames, IA

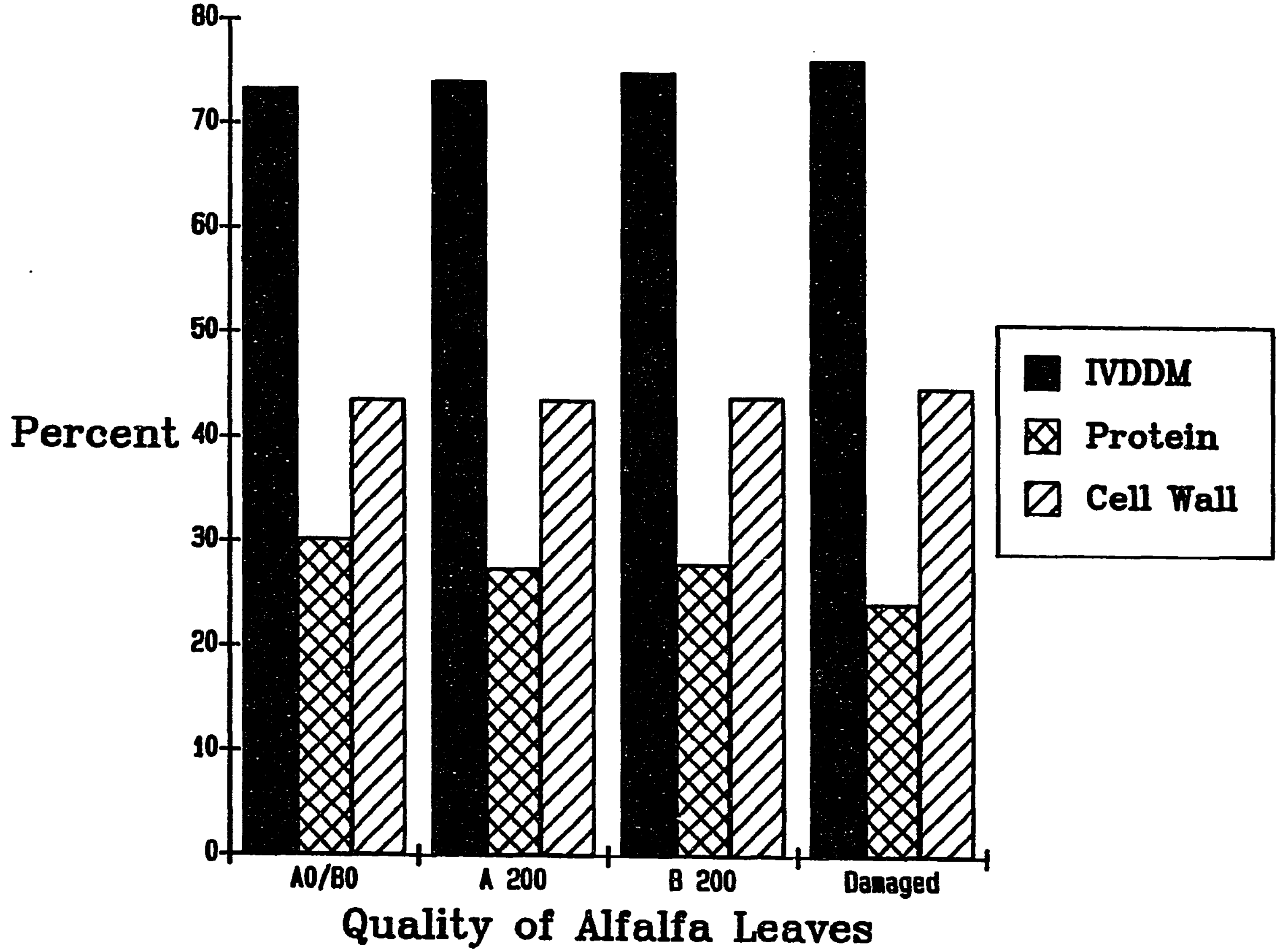
		Forage Protein			Stem Protein			Leaf Protein		
Infest Period	PLH Density	14	28	HAR	14	28	HAR	14	28	Har
A	0	29.68	24.68	20.98	23.90	15.39	14.30	42.41	31.78	29.66
	50	29.98	22.83	21.80	25.68	15.39	15.29	42.69	32.27	28.00
	100	29.98	23.23	21.35	26.13	16.03	14.30	43.30	31.46	27.53
	200	30.09	21.53	20.03	25.65	16.81	14.61	42.39	29.20	27.46
B	0	30.58	24.71	21.88	24.86	16.23	14.39	41.68	31.94	30.83
	50	29.60	25.22	21.77	26.21	16.50	14.87	40.83	31.33	30.53
	100	31.10	23.86	21.23	24.76	16.56	14.50	41.35	31.66	29.33
	200	29.22	23.44	21.26	25.49	17.03	15.41	42.35	30.22	27.93
Contrasts:[a]										
A: 0 vs 50-200		ns	*	ns	*	ns	ns	ns	ns	**
A: 0-100 vs 200		ns	*	*	ns	**	ns	ns	**	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	*
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns	*
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	*	**
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		ns	**	ns	ns	*	ns	ns	ns	**

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

limiting characteristic of a forage.

The leaf chlorosis resulting from PLH feeding will affect the photosynthetic potential of the leaf and likely act to reduce the overall biomass yield of the plant. The impact of "hopperburn" on digestibility, cell-wall concentration, and crude protein of individual leaves, however, is largely unknown. In addition, the quality reductions are frequently only associated with visibly chlorotic leaves, however leaves subjected to PLH feeding but not exhibiting chlorosis are frequently overlooked. Figure 2.3 presents data for leaves demonstrating chlorosis (labelled as damaged), leaves from early and late infested plots but not demonstrating chlorosis (labelled as A-200 and B-200, respectively), and leaves from uninfested plots (labelled as A-0/B-0). The visibly damaged leaves were seen to increase in digestibility compared to the leaves in the uninfested plots. The levels of leaf protein, in contrast, decreased within the infested plots. Cell-wall concentration remained stable for leaves, regardless of injury status. These data suggest, albeit indirectly, that carbohydrates are composing the chlorotic portions of the leaf at the exclusion of proteins. Perhaps translocative blockage is preventing the transport of carbohydrates for conversion to proteins. An alternate hypothesis is that the injury to the leaves by PLH feeding may be disrupting hormonal production in the leaves which would reduce protein levels. If auxin hormones were disrupted, then stunting from reduced stem elongation, which is frequently associated with lower levels of auxins, could be partially accounted for. These explanations are

Figure 2.3. The effect of potato leafhopper feeding on the chemical composition (digestibility [IVDDM], cell-wall concentration, and crude protein) of alfalfa visibly injured and infested but not visibly injured (labelled as A200 and B200 for early and late infested, respectively). Ames, IA


Percent
80
70
60
50
40
30
20
10
0
A0/B0
A 200
B 200
Damaged
Quality of Alfalfa Leaves
IVDDM
Protein
Cell Wall

speculative and would require further experimentation to confirm or dismiss. Nevertheless, close evaluation of plant components in these field trials has provided possible directions for physiological research which are largely unexplored.

To more closely associate the results of the quality assays with animal production, calculated parameters of forage utilization were employed. Digestible dry matter intake (DDMI) has been proposed as a parameter which accounts for the digestibility and intake characteristics of a feed (Van Soest 1982). In these experiments, the PLH-induced injury to the plots does not consistently reduce the DDMI (Table 2.4). Comparisons of individual plant components indicates that DDMI is largely unaltered in the stem component, but leaves injured from a late infestation maintain a significantly lower DDMI than leaves infested early. This may be a result of premature leaf drop in the early infested plots, which was not observed in plots infested later.

An additional measure of forage value is the relative feed value (RFV). As with DDMI, the RFV is not significantly altered when compared over all trials (Fig. 2.4). These values reflect the minor differences in digestibility seen with PLH feeding. The leaf component is largely unaffected in terms of RFV to the ruminant (Table 2.5). Although RFV provides a useful index to compare an array of forages, this parameter is less amenable to economic comparisons in utility, because it fails to report differences in substitution units (e.g., kg of soybean meal).

Table 2.4. Effect of various infestation periods and densities of potato leafhopper (PLH) on the forage, stem, and leaf potential digestible dry matter intake (gm/w kg -0.75) of alfalfa measured at harvest for each of three field trials. Ames, IA

		Forage DDMI			Stem DDMI			Leaf DDMI		
Infest Period	PLH Density	1984	1985A	1985B	1984	1985A	1985B	1984	1985A	1985B
A	0	123.70	126.42	112.81	86.71	79.01	77.09	90.27	60.28	84.02
	50	119.06	128.75	117.58	89.20	78.88	78.56	91.53	64.26	82.31
	100	117.58	127.60	120.24	86.75	81.79	74.95	88.67	73.46	80.91
	200	115.18	123.88	122.45	89.58	83.18	80.39	91.74	61.50	81.22
B	0	128.14	120.66	116.08	86.88	84.65	75.65	81.13	69.85	79.55
	50	126.41	126.05	120.34	87.66	79.77	74.87	74.28	69.34	77.04
	100	120.26	124.95	116.03	86.31	81.23	77.57	77.07	77.29	83.27
	200	125.03	127.87	115.53	90.32	84.48	81.23	75.32	83.12	81.77
Contrasts:[a]										
A: 0 vs 50-200		*	ns	*	ns	ns	ns	ns	ns	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	*	ns	ns	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		**	ns	ns	ns	ns	ns	**	*	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

Figure 2.4. Effect of various infestation periods and densities of potato leafhopper on the relative feed value of alfalfa. Ames, IA

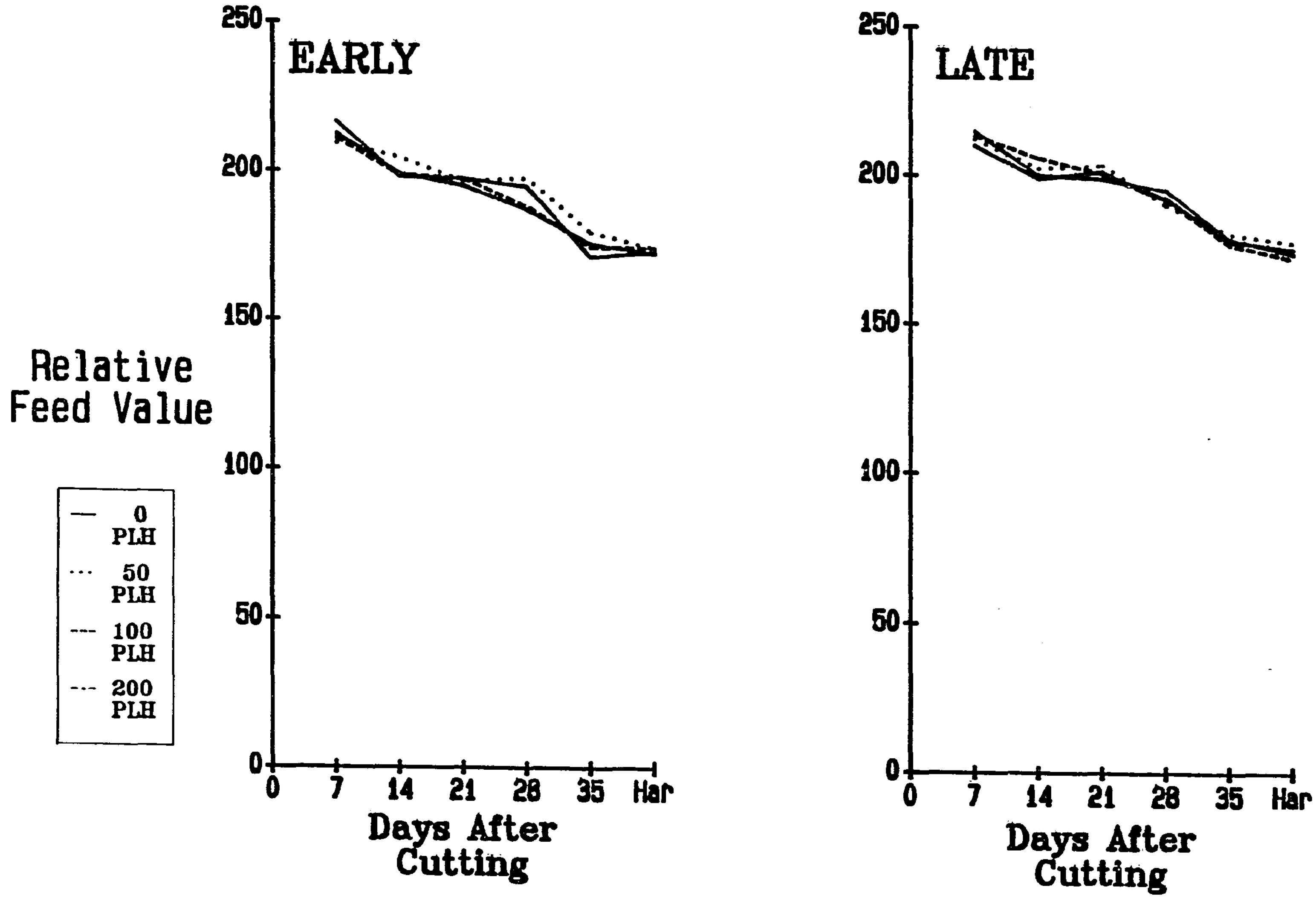

EARLY
LATE
Relative Feed Value
250
200
150
100
50
0
0
7
14
21
28
35
Har
Days After Cutting
— 0 PLH
··· 50 PLH
--- 100 PLH
-·- 200 PLH

Table 2.5. Effect of various infestation periods and densities of potato leafhopper (PLH) on the stem and leaf relative feed value of alfalfa measured at harvest for each of three field trials. Ames, IA

		Stem Relative Feed Value				Leaf Relative Feed Value			
Infest Period	PLH Density	1984	1985A	1985B	Overall	1984	1985A	1985B	Overall
A	0	123.88	112.87	110.13	115.63	129.00	86.11	120.03	111.70
	50	127.43	112.69	112.22	117.45	130.80	91.80	117.59	113.39
	100	123.94	116.84	107.08	115.95	126.70	104.95	115.59	115.74
	200	127.97	118.84	114.84	120.55	131.10	87.86	116.03	111.65
B	0	124.12	120.93	108.08	117.71	115.90	99.79	113.64	109.78
	50	125.24	113.96	106.96	115.39	106.10	99.06	110.07	105.08
	100	123.30	116.04	110.81	116.72	110.10	110.41	118.96	113.15
	200	129.03	120.69	116.05	121.92	107.60	118.75	116.81	114.39
Contrasts:[a]									
A: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
A: 0-100 vs 200		ns	ns	ns	*	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	*	**	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		ns	ns	ns	ns	**	*	ns	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

Perhaps the best measure of forage utility to the animal is the calculated measure of available digestible energy per mass of feed. This value, reported as Mcal, can be compared to similar feeds and utilized in least cost rations or economic decision-making frameworks. The potential level of digestible energy per mass was not affected by PLH feeding (Fig. 2.5) in this experiment. There is an expected general decline in the available energy as lignification progresses over time, but the levels among treatments are not significantly different. Likewise, there are few significant reductions in the levels of digestible energy from the individual components of the plants (Table 2.6). The stem-to-leaf ratio of digestible energy is altered in favor of the leaves (compared to uninfested plots), reflecting the increased contribution of this component in the final forage.

Management Implications

Feeding by the PLH does not seem to alter the nutritional value of alfalfa when measured on a per unit basis. Inasmuch as PLH feeding is a form of plant stress, this conclusion is somewhat predictable. The primary factor mitigating against increased quality of a forage is plant maturation (Van Soest 1982). Seemingly, PLH stress acts to slow the rate of growth, and hence maturation of the plants. This reduced rate of maturation results in a concomitant reduction in lignification (especially in the stems).

Figure 2.5. Effect of various infestation periods and densities of potato leafhopper on the available digestible energy of alfalfa (Mcal/kg of alfalfa). Ames, IA

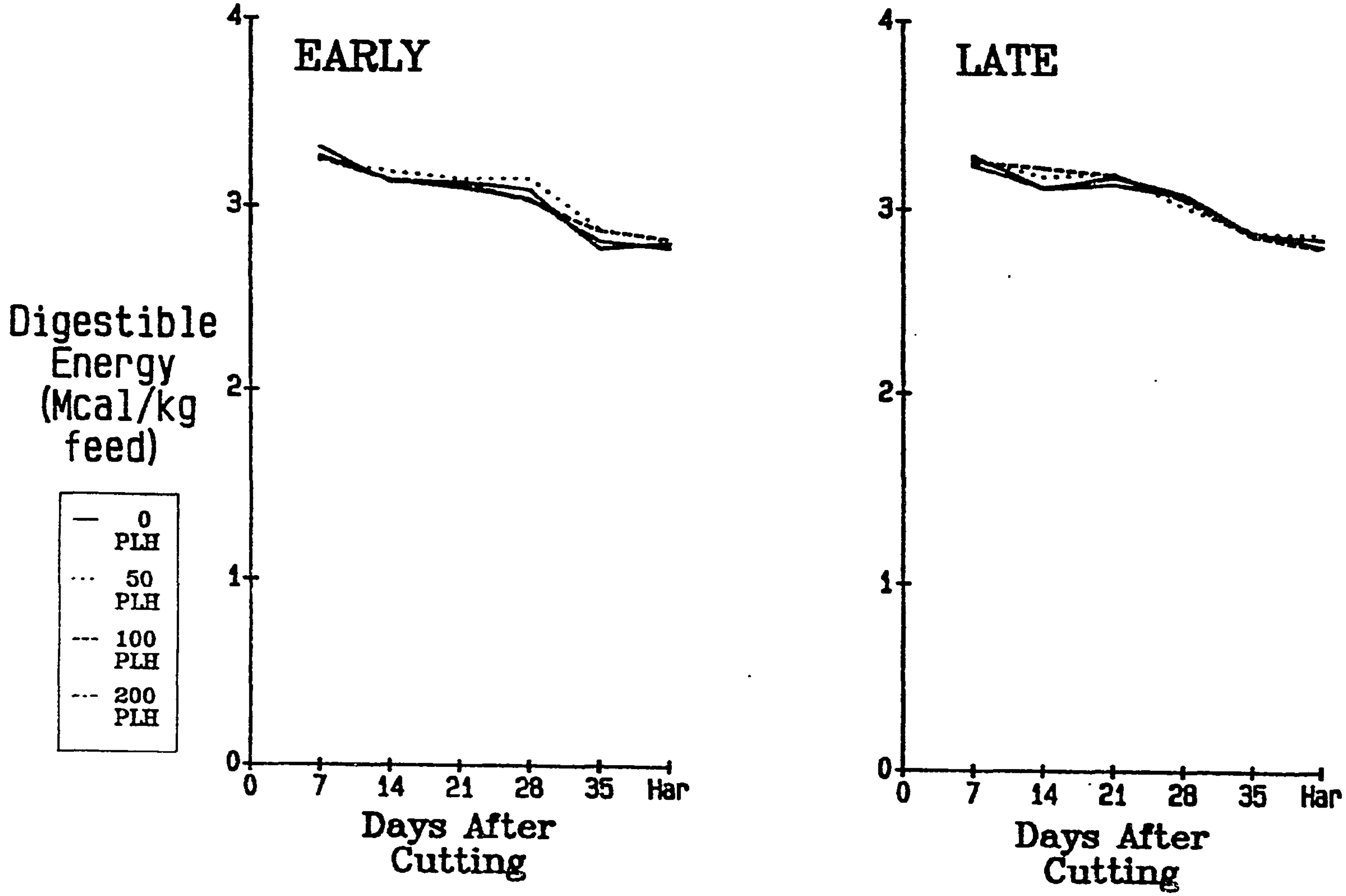

EARLY
LATE
Digestible Energy (Mcal/kg feed)
0 PLH
50 PLH
100 PLH
200 PLH
0
1
2
3
4
0 7 14 21 28 35 Har
Days After Cutting

Table 2.6. Effect of various infestation periods and densities of potato leafhopper (PLH) on the stem and leaf digestible energy (DE, Mcal/kg feed) and ratio of stem to leaf DE of alfalfa at three sample periods and over three field trials. Ames, IA

		Stem DE			Leaf DE			Stem:Leaf DE		
Infest Period	PLH Density	14	28	HAR	14	28	HAR	14	28	Har
A	0	3.13	2.65	2.38	3.47	3.28	3.16	0.90	0.81	0.76
	50	3.17	2.74	2.41	3.43	3.30	3.16	0.93	0.83	0.76
	100	3.20	2.79	2.35	3.40	3.32	3.08	0.94	0.84	0.77
	200	3.22	2.72	2.44	3.40	3.34	3.15	0.95	0.82	0.78
B	0	3.17	2.75	2.42	3.47	3.23	3.08	0.92	0.85	0.79
	50	3.18	2.75	2.36	3.42	3.29	3.11	0.93	0.83	0.76
	100	3.13	2.77	2.40	3.42	3.36	3.06	0.92	0.83	0.79
	200	3.17	2.75	2.49	3.48	3.33	3.18	0.91	0.83	0.78
Contrasts:[a]										
A: 0 vs 50-200		ns	*	ns	ns	ns	ns	*	ns	ns
A: 0-100 vs 200		ns	ns	ns	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	**	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	**	ns	ns	**	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		ns	ns	ns	ns	ns	ns	ns	ns	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

The conclusion that forage quality is not greatly affected does not suggest that alfalfa production is unaltered by PLH feeding. Large decreases in biomass yield can accrue as a result of injury, and these decreases will result in an overall reduction in nutritional yield. From a management perspective, therefore, sampling and management of this pest should revolve around the physical yield of nutrients, rather than quality per unit of yield. For example, the losses in digestible-energy yield should be measured and reported as Mcal/ha of land instead of Mcal/kg of feed. With the realization that PLH feeding does not reduce quality per unit of yield, and may actually increase the digestibility per unit of yield, a PLH pest management system for alfalfa can be simplified to focus on the biomass damage functions.

PART III. PHENOLOGICAL DISRUPTION, NUTRIENT YIELDS, AND ECONOMIC CONSEQUENCE OF POTATO LEAFHOPPER-INDUCED INJURY TO ALFALFA

ABSTRACT

Research designed to identify and quantify the injury syndrome of alfalfa subjected to potato leafhopper (PLH), *Empoasca fabae* (Harris), feeding were implemented in 1984 and 1985. A total of three field trials were conducted using a split-plot in time design. Wholeplots consisted of a factorial arrangement of four PLH densities (0, 50, 100, and 200 adults per m^2) and two infestation periods (1 and 14 days into second regrowth). Subplots represented weekly insect and destructive plant samples. Growth and development data from the plant samples were combined with quality parameters (digestibility, cell-wall concentration, crude protein, and digestible energy) to determine nutrient yields for all plots. An analysis of variance was conducted to determine treatment differences, and regression analysis was employed to determine the rates of development and correlation with PLH density.

A significant reduction in the rate of phenological development was identified. This delay resulted in a concomitant reduction in the daily accumulation of nutrient yield. There was evidence, however, that much of the loss could be compensated for with additional regrowth time. Therefore, for economic comparisons, harvest at the predicted date of first bloom was compared to a calendar-date harvest schedule (where all plots were harvested when the uninfested plots reached first bloom). For the calendar-date schedule, PLH feeding caused significant economic losses. The damage-per-unit-of-injury function was based on the strong relationship of nutrient yield with days following harvest. The injury-

per-insect relationship necessary for the economic-injury levels was based on the high correlation of PLH feeding with phenological delay. Feasible management costs and substitution market prices were used to calculate significant economic delays. Economic-injury levels were calculated based on nutrient substitution prices with soybean meal and dry matter prices for hay.

INTRODUCTION

The potato leafhopper (PLH), Empoasca fabae (Harris), has long been considered a serious pest of agricultural crops (Osborn 1896). In the North Central United States, however, the PLH is most frequently implicated as causing yield and quality reductions in alfalfa, Medicago sativa L. Indeed, in many years the PLH may be the only insect species capable of causing significant economic losses (Smith and Ellis 1983). Injury to the plant is in the form of phloem destruction and clogging by debris during feeding from repeatedly inserting the stylet. Reductions in dry matter and plant height are among the most commonly documented yield responses to PLH feeding (Faris et al. 1981), and in some instances the physiological basis for yield loss has been investigated. Ladd and Rawlins (1965) noted a long-term reduction of 30 to 40% in photosynthetic activity and a short-term decrease in respiration following PLH feeding. Although many studies have investigated specific aspects of PLH-induced injury to the crop, few studies have extended their conclusions for the calculation of economic decision indices. Moreover, most pest density/crop damage relationships currently established fail to adjust the crop response for differences in plant maturity.

Economic-injury levels require both economic and biological data (Pedigo et al. 1986). First, some estimate of the economic worth of the crop is necessary to evaluate its relative utility to the grower. In most instances, a simple market value can be utilized here, but with alfalfa a more precise estimate of utility must be determined based on available nutrients. For example, the value of alfalfa in a feeding ration may be the available digestible energy, as opposed to the crude protein. In such a case, the substitution value of a Mcal of digestible energy should be determined and used to gauge the injuriousness of a pest population. Second, a value for the management costs must be determined to weigh against the market value. In addition to these economic variables, two biological values must be determined; namely, the damage to the crop per unit of injury, and the injury per insect. Inasmuch as alfalfa has biomass and quality components, the injury syndrome should reflect the composite value of the forage.

The objective of this study is to investigate the primary mode of injury for PLH on alfalfa, and to quantify the relationship. In addition, the host response to the PLH-induced injury will be determined based on nutrient yields of digestible energy, crude protein, cell-wall concentration, and dry matter. Finally, these two biological characterizations will be used to calculate economic-injury levels for PLH on alfalfa. Emphasis will be placed on the production and harvest schedules (i.e., first-bloom harvest vs. calendar-date harvest), and will reflect the duration as well as the density of a PLH infestation.

MATERIALS AND METHODS

Experiments designed to identify and characterize plant physiological response of alfalfa to PLH-induced injury were conducted in 1984 (one trial) and 1985 (two trials). 'Blazar' alfalfa was seeded in a 2.3-ha field on the Johnson Research Farm near Ames, Iowa. On 25 April 1984, all plots were drill-planted in 17.5-cm rows at the rate of 15.7-kg of seed per hectare following an earlier application (20 April 1984) of Eptam® to suppress grass weed species during stand establishment. The field was topdressed annually with 135 kg/ha of P and 225 kg/ha of K prior to growth each Spring. Management practices consistent for alfalfa production in central Iowa were followed, and daily temperature and rainfall data were recorded at National Oceanic and Atmospheric Administration weather station 0200-05 (ca. 12-km west of the plots).

During the establishment year of 1984, the field was undisturbed until 14 July, when all plant material was cut to a height of 6.4-cm, and the plot area was raked to remove residual plant debris. Subsequently, thirty-two experimental plots encompassing a 1-m x 2-m land area were established according to a randomized complete block design with four replications. Each of the four blocks consisted of a factorial 4 x 2 arrangement of four PLH densities (0, 50, 100, and 200/m^2) and two infestation periods (1 day following harvest or 14 days following harvest). A Saran® cage (1-m x 2-m x 1-m tall) was installed over the plots randomly designated to be infested early. PLH adults were collected from an adjacent field of glabrous soybean (isoline of 'Clark') with a D-Vac® vacuum insect net and returned to the laboratory. The insect samples were placed in plexiglass cages and aspirated into glass test tubes in quantities of 50 for artificial infestation of the caged plots. Following an oviposition interval of 14 days to establish nymphal populations, the cages were moved to the remaining plots and infested by the same procedure. After the 14-day oviposition period elapsed, all cages were removed from the field. The caging interval was deliberately limited to 14 days to minimize any adverse or unnatural shading effect on the plants. The field area adjacent to the plots was monitored regularly to insure that transitory feeding from native PLH populations did not occur. Moreover, the adjacent glabrous soybean planting is believed to have attracted nearby native populations away from the uncaged plots.

In 1985, the first trial (1985A) was initially infested on 2 July, and the second field trial (1985B) was infested on 31 July. These trials were conducted in the same field as in 1984, but in different locations within the field. All other procedures were followed as in 1984.

To monitor the temporal development of the insect and crop, a split-plot in time was superimposed on the field design. Subplots represented weekly destructive plant samples collected from one-half of the plot area (1-m x 1-m). The destructive samples actually consisted of three individual bouquets of stem samples. The remaining half of the plot area was utilized for weekly stem density counts and for final yield measurements.

A 9-stem bouquet was collected from each plot and carefully placed in a carton with dichlorovos-impregnated insecticide strips (Simonet et al. 1978). The PLH nymphs dislodged from the stems within 48 hours, and numbers were recorded for future analysis. A second stem sample, consisting of 25 stems, was collected and prepared for quality determinations including: in-vitro digestible dry matter analysis (Tilley and Terry 1963), neutral-detergent fiber analysis to determine cell-wall concentration (Van Soest and Wine 1967), and micro-Kjeldahl analysis to determine percent nitrogen and crude protein (Bremner and Mulvaney 1982). Individual quality assays also were performed on the individual leaf and stem components. A final bouquet, consisting of 15 stems, was collected and returned to the laboratory for physical measurements of growth. Specifically, the following growth and yield measurements were recorded: stage of morphological development (Kalu and Fick 1981), stem height and weight, and leaf area (using a LiCor® model 3000 planimeter), and weight. Values for nutritional yield were calculated based on biomass harvest and quality assessments. For example, the dry matter per ha multiplied by the proportion of dry matter which is digestible, provided the digestible dry matter yield per ha.

Statistical Comparisons and Economic Evaluations

All measurements for plant growth and development (Appendix B), including the calculated measurements described in Appendix A, were analyzed by year and sample date with an analysis-of-variance (ANOVA) procedure and a least-significant-difference determination. The results of these analyses are presented in Appendix C (biomass yield and growth rate variables), Appendix D (quality assays), and Appendix E (nutritional yield values). An ANOVA over all years by sample date (days 7, 14, 21, 28, and 35) and at second harvest (2-Har) also was conducted, with whole-plot differences determined with orthogonal comparisons. Specific comparisons (labelled as infestation period A or B: PLH densities) included: A: 0 versus 50-200, A: 0-100 versus 200, A: 0 versus 50, B: 0 versus 50-200, B: 0-100 versus 200, B: 0 versus 50, A versus B: 50-200. In addition, regression models were constructed to predict the date of first bloom based on morphological development. Also, the predicted status of nutrient yield was modelled with regression techniques.

Economic comparisons were made based on static sample date values and on predicted date of first-bloom criteria. The former, referred to as the calendar-date harvest system, compares all treatments to the check plot harvested at first bloom. The first-bloom harvest comparisons evaluate PLH-induced losses by evaluating nutritional yield when all plots reach first-bloom status.

RESULTS AND DISCUSSION

Weekly PLH population counts determined from the 9-stem bouquet indicated that the desired gradation in pest pressure was achieved (Fig. 3.1). Hence, the measures taken to limit the shading of the plots apparently had no significant effect on the establishment of the nymphal population. Moreover, the extremely low level of individuals found in the uninfested plots suggests that the efforts to limit transitory feeding within the uncaged plots were successful. The nymphal population was increased in the early infested plots through the 35-day sample interval and then declined. Nymphal populations in the late infested plots continued to climb through harvest. The relative magnitude of the increase was similar among the plots, suggesting that crowding or intraspecific competition did not occur to any great extent.

Crop Physiology and Nutrient Yields

A significant reduction in the rate of phenological development was observed. The slope of phenological development through time provided a means for quantifying PLH injury to the developmental physiology of the crop. Regression analysis, using days after harvest to predict stage of development and the three field trials as replicates, resulted in significant correlation coefficients for each PLH density and infestation period combination (Table 3.1). Analysis to describe the functional form of the relationship demonstrated that the data were best described with a

Figure 3.1. Number of potato leafhopper, *Empoasca fabae* (Harris), nymphs sampled at weekly intervals in second regrowth alfalfa. Numbers are means of three field trials conducted in 1984 and 1985. Ames, IA

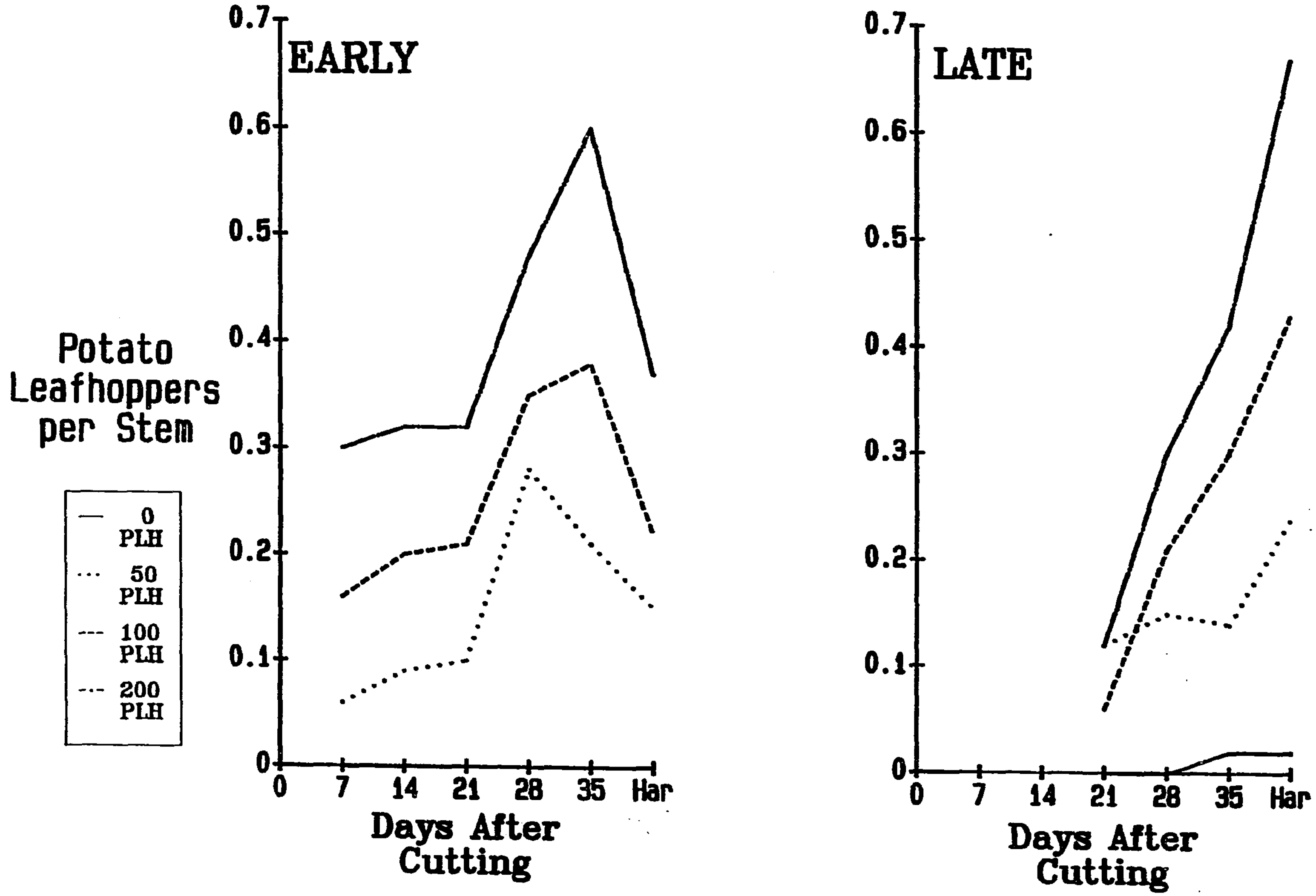

EARLY
LATE
Potato Leafhoppers per Stem
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
7
14
21
28
35
Har
Days After Cutting
0 PLH
50 PLH
100 PLH
200 PLH

Table 3.1. Effect of PLH-induced injury on alfalfa development, and yield development of dry matter (DM), crude protein (CP), cell wall, and digestible energy (DE). Linear regressions forced through the origin and using trials as replicates

Infest Period	PLH Density		Developmental Stage	DM	CP	Cell Wall	DE
A	0	slope	0.083a[a]	129.60a	29.78a	74.45a	378.76a
		SE	0.003	4.70	1.40	2.88	15.35
		r	0.81	0.78	0.60	0.79	0.72
	50	slope	0.065bc	97.35b	22.02b	56.04c	287.06b
		SE	0.002	3.07	0.85	2.12	9.57
		r	0.79	0.84	0.72	0.82	0.81
	100	slope	0.064bc	93.86b	21.12b	55.25c	274.68b
		SE	0.003	3.55	0.97	2.16	11.16
		r	0.77	0.76	0.60	0.77	0.71
	200	slope	0.058c	91.55b	20.18b	52.21c	266.22b
		SE	0.003	3.84	1.10	2.30	11.76
		r	0.73	0.75	0.55	0.75	0.70
B	0	slope	0.081a	124.12a	29.62a	66.23ab	364.81a
		SE	0.002	4.88	1.39	3.00	15.56
		r	0.92	0.74	0.59	0.73	0.69
	50	slope	0.068b	89.44b	21.52b	49.96c	265.45b
		SE	0.002	3.06	1.00	1.73	10.18
		r	0.88	0.78	0.58	0.80	0.72
	100	slope	0.067b	104.40b	24.14b	59.74bc	307.62b
		SE	0.002	3.98	1.12	2.22	12.76
		r	0.85	0.76	0.58	0.79	0.69
	200	slope	0.064bc	94.68b	21.76b	54.13c	280.05b
		SE	0.002	3.18	1.05	1.84	10.35
		r	0.82	0.79	0.55	0.81	0.73
F-value			8.83	6.25	7.23	4.64	6.31

[a]Slopes within columns followed by the same letter are not significantly different (P=0.05) based on Student-Newman-Keuls multiple range test; df=7,14. All correlation coefficients are significant (P=0.05).

linear function. In addition, the Y-intercept term was not found to be significantly different from zero, so the regression lines were forced through the origin. The noted delays in development were present at all levels of PLH infestation, but there was no significant difference among PLH density plots within an infestation period.

Similar regression techniques were applied to the nutrient yield variables also presented in Table 3.1. Dry matter (DM), crude protein (CP), cell-wall concentration, and calculated digestible energy (DE) were also significantly reduced in development from PLH feeding. In each instance, the infested plots accumulated these components at a significantly reduced rate compared to development of the uninfested plots. As with phenological development, the correlation coefficient for the model was significant, and the slope was different from zero.

Values for developmental slopes in Table 3.1 were used to calculate the status of plots at different phenological stages of development. This procedure provided a technique for normalizing the noted differences in rate of morphological development. Table 3.2 provides the predicted date of first bloom for all the plots. In addition, the predicted yields for DM, CP, cell-wall, and DE per ha are also indicated. For the early infestation, there were significantly fewer growing days required to reach first bloom in the uninfested plots compared to the infested plots. In addition, the highest infestation rate required significantly more days to develop than the other infestation rates. Differences among treatments within the late infested plots were not statistically

Table 3.2. Effect of various infestation periods and densities of potato leafhopper (PLH) on the calculated date of 1/10 bloom (days after cutting) and yields of dry matter (DM, kg/ha), crude protein (CP, kg/ha), cell wall (kg/ha), and digestible energy (DE, Mcal/ha) at estimated date of alfalfa first bloom. Ames, IA

Infest Period	PLH Density	Predicted first bloom	Yield			
			DM	CP	Cell Wall	DE
A	0	36.1	4678.7	1075.1	2687.5	13673.0
	50	46.2	4497.4	1017.3	2588.9	13262.0
	100	46.9	4505.4	1013.6	2652.1	13185.0
	200	51.7	4486.1	988.7	2558.1	13045.0
B	0	37.0	4654.0	1110.9	2596.0	13680.0
	50	44.1	3845.9	925.4	2148.1	11414.0
	100	44.8	4541.5	1050.1	2598.7	13381.0
	200	46.9	4506.9	1035.8	2576.4	13330.0
Contrasts:[a]						
A: 0 vs 50-200		**	ns	ns	ns	ns
A: 0-100 vs 200		*	ns	ns	ns	ns
A: 0 vs 50		ns	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns
A vs B: 50-200		ns	ns	ns	ns	ns

[a]*F* values for contrasts determined to be significant (*, *P*=0.05), highly significant (**, *P*=.01), or not significant (ns).

significant. Similarly, differences in nutrient yields were not obvious when all plots were extrapolated to first bloom. This suggests that, given additional time, the PLH-injured alfalfa will compensate for much of the difference in nutrient yield.

Nutrient yield comparisons on a straight calendar-date harvest basis are presented in Table 3.3. For this analysis, all plots were harvested when the control plots reached the first bloom stage. Therefore, because of the noted delays in phenological development, the infested plots were considerably less mature. In nearly every instance, significant reductions in DM, CP, cell-wall, and DE harvests were recorded. There were no nutrient yield differences between plots infested early and late, and in both situations the lowest PLH density produced significant reductions in each nutrient yield category.

The specific plant component contributions to nutrient yields at three sample intervals are presented in Table 3.4. The leaf-to-stem ratios for crude protein yields suggest that the relative contribution of stem component is reduced with PLH feeding at 28-days post infestation. This likely reflects the reduced stem height of the injured plants at that time, without a concomitant reduction in the number or mass of leaf tissue. By the final sample period, however, the differences had reversed so that the stem component contributed more to overall protein yield than the leaf component (relative to the uninfested plots). This reversal suggests that the stem component was able to partially compensate for early losses. In addition, the leaf tissue experienced a

Table 3.3. Effect of various infestation periods and densities of potato leafhopper (PLH) on the yields of dry matter (DM, kg/ha), crude protein (CP, kg/ha), cell wall (kg/ha), and digestible energy (DE, Mcal/ha) of alfalfa measured on a calendar date harvest (based on first bloom of uninfested plots). Ames, IA

Infest Period	PLH Density	Yield			
		DM	CP	Cell Wall	DE
A	0	4678.7	1075.1	2687.5	13673.0
	50	3519.7	789.0	2022.3	10374.9
	100	3404.3	757.8	2001.0	9962.1
	200	3293.1	716.9	1875.2	9567.4
B	0	4654.0	1110.9	2596.0	13680.0
	50	3253.5	779.6	1811.8	9657.9
	100	3780.5	870.0	2154.2	11128.3
	200	3406.3	779.7	1944.8	10076.7
Contrasts:[a]					
A: 0 vs 50-200		**	**	**	**
A: 0-100 vs 200		*	**	*	*
A: 0 vs 50		**	**	**	**
B: 0 vs 50-200		**	**	**	**
B: 0-100 vs 200		ns	*	ns	ns
B: 0 vs 50		**	**	**	**
A vs B: 50-200		ns	ns	ns	ns

[a]*F* values for contrasts determined to be significant (*, *P*=0.05), highly significant (**, *P*=.01), or not significant (ns).

Table 3.4. Effect of various infestation periods and densities of potato leafhopper (PLH) on the the leaf:stem yield ratios for crude protein (CP), digestible energy (DE), and cell wall of alfalfa measured at three sample dates over three field trials. Ames, IA

Infest Period	PLH Density	CP leaf:stem 14	CP leaf:stem 28	CP leaf:stem HAR	DE leaf:stem 14	DE leaf:stem 28	DE leaf:stem HAR	Cell Wall leaf:stem 14	Cell Wall leaf:stem 28	Cell Wall leaf:stem HAR
A	0	1.27	1.37	1.37	0.78	0.81	0.89	0.93	0.97	1.04
	50	1.27	1.75	1.16	0.83	1.02	0.84	0.99	1.14	1.02
	100	1.23	1.54	1.23	0.81	0.93	0.85	1.02	1.04	1.02
	200	1.23	1.47	1.10	0.79	1.03	0.82	0.96	0.97	1.08
B	0	1.32	1.43	1.35	0.86	0.88	0.80	1.09	1.14	1.01
	50	1.32	1.41	1.45	0.90	0.91	0.92	1.23	0.96	1.15
	100	1.41	1.54	1.25	0.93	0.98	0.79	1.16	1.10	0.97
	200	1.27	1.45	1.16	0.84	1.01	0.82	1.11	0.96	1.03
Contrasts:[a]										
A: 0 vs 50-200		ns	*	*	ns	**	ns	ns	ns	ns
A: 0-100 vs 200		ns	*	*	ns	ns	ns	ns	ns	ns
A: 0 vs 50		ns	**	*	ns	**	ns	ns	ns	ns
B: 0 vs 50-200		ns	ns	ns	ns	ns	ns	ns	ns	ns
B: 0-100 vs 200		ns	ns	*	ns	ns	ns	ns	ns	ns
B: 0 vs 50		ns	ns	ns	ns	ns	ns	ns	ns	ns
A vs B: 50-200		ns	ns	*	**	ns	ns	**	ns	ns

[a]F values for contrasts determined to be significant (*, P=0.05), highly significant (**, P=.01), or not significant (ns).

natural decline in protein as the plants continued to mature.

Differences in the partitioning of available DE between the leaf and stem components was less affected (Table 3.4). There was a relatively larger proportion of DE contained in the leaf tissue at 28-days post infestation, but this difference disappeared by late harvest. The cell-wall concentration remained stable among the plant components throughout the sample period.

Economic Consequence of Physiological Delay

Inasmuch as alfalfa is a perennial species with multiple harvests each year, the economic interpretation of PLH-induced growth delays is difficult. Indeed, alfalfa has no widely recognized market price from which pest control tactics can be evaluated, and many times the crop is used for on-farm livestock production. Therefore, equivalent substitution values for alfalfa, based on documented nutritional contents (National Research Council 1978a) and current market prices for soybean meal, were calculated. For example, the value of a single Mcal of digestible energy for alfalfa was presumed to equal a single Mcal for purchased soybean meal. Comparisons to local market values for hay (two feasible prices for central Iowa) were also determined for reference to the dry matter value of the crop.

The relative impact on economic returns from PLH feeding was determined for both the first bloom and calendar-date harvest systems. There were no significant differences among the treatments in dollar returns per hectare when all plots were extrapolated to first bloom

(Table 3.5). However, when the value of the harvestable nutrient yields were evaluated on a calendar-date basis (i.e., all plots harvested when the uninfested plot reached first bloom), significant economic losses were observed. For DE, all PLH densities resulted in lower returns per hectare. The equivalency relationship with soybean meal also resulted in significant losses for all infested plots harvested on a calendar-date basis. The DM value of the calendar-date harvested alfalfa was also significantly affected by PLH feeding.

Based on the substitution values of alfalfa with soybean meal, the DE contribution of alfalfa is of greatest value for protection from PLH-induced reductions. The CP value is second, followed by the DM qualities of the crop. In other words, if each of these nutritional qualities are in equal demand by the ruminant consumer, then the PLH-induced reductions in DE should receive priority management consideration. It follows, then, that the DE aspect of nutritional yield should be incorporated into the calculation of economic-injury levels.

Management Strategies

The strong correlations of phenological development with days of regrowth for each PLH treatment provide a uniform response of PLH-induced injury to the crop. The uniformity results from the association of nutrient yield with physiological development and maturity. Therefore, managing nutrient yield losses to the crop requires a predictable association of PLH density with observed delay. Regression equations to

Table 3.5. Effect of various infestation periods and densities of potato leafhopper (PLH) on the returns ($) per hectare for alfalfa compared to replacement feeds of soybean meal (SBM, $/kg) for digestible energy (DE) and crude protein (CP), and hay (HAY, $/kg) for dry matter (DM) at the predicted date of first bloom and on a calendar date harvest system (based on date of first bloom for uninfested plots. Ames, IA

		$0.1929 SBM		$0.0610 HAY	$0.2480 SBM		$0.0770 HAY
Infest Period	PLH Density	DE	CP	DM	DE	CP	DM
		Value measured on 1/10 bloom basis					
A	0	738.4a[a]	418.2a	285.4a	957.1a	537.1a	360.3a
	50	716.2a	395.7a	274.3a	928.4a	508.7a	346.3a
	100	712.0a	394.3a	274.8a	922.9a	506.8a	346.9a
	200	704.4a	384.6a	273.7a	913.1a	494.3a	345.4a
B	0	738.8a	432.1a	283.9a	957.6a	555.4a	358.4a
	50	616.4a	360.0a	234.6a	799.0a	462.7a	296.1a
	100	722.6a	408.5a	277.0a	936.7a	525.0a	349.7a
	200	719.8a	402.9a	274.9a	933.1a	517.9a	347.0a
F-value		0.95	0.89	1.01	0.95	0.89	1.01
		Value measured calendar date harvest basis					
A	0	738.4a	418.2a	285.4a	957.1a	537.1a	360.3a
	50	560.2b	306.9bc	214.7b	726.2b	394.5bc	271.0b
	100	538.0b	294.8bc	207.7b	697.4b	378.9bc	262.0b
	200	516.6b	278.9c	200.9b	669.7b	358.4c	253.6b
B	0	738.8a	432.1a	283.9a	957.6a	555.4a	358.4a
	50	521.5b	303.5bc	198.5b	676.1b	389.8bc	250.5b
	100	600.9b	338.4b	230.6b	779.0b	435.0b	291.1b
	200	544.1b	303.3bc	207.8b	705.4b	389.8bc	262.3b
F-value		6.99	7.71	6.98	6.99	7.71	6.98

[a]Means within columns followed by the same letter are not significantly different (P=0.05) according to Student-Newman-Keul's multiple range test; df=7,14.

describe this relationship are presented in Table 3.6. Separate equations are provided for early and late infestations, and for PLH measured per m^2 and per stem. In addition, overall equations are provided to describe the general relationship for instances when the time of infestation is not known. In all of these models the Y-intercept was not significantly different from zero so the regression line was forced through the origin. In addition to being statistically appropriate, forcing the model through the origin is pragmatic because the absence of PLH feeding should not allow for a crop delay. All models resulted in a significant correlation coefficient.

With knowledge of the association between PLH density and crop delay established, economic-injury levels were determined. The graphical representation for these determinations is presented in Fig. 3.2. In the main portion of the graph, the differential relationships in rate of development can be seen for two PLH densities (0 and 200 PLH/m^2, early infestation). The slower rate of infested plants essentially results in fewer Mcal of digestible energy (vertical axis) accumulated per day (horizontal axis). For a harvest system based on first bloom, the final yield loss is diminished as the injured plants eventually compensate for most of the early reductions. For a calendar-date harvest system, where time is more limiting, the losses in DE are much more severe (measured at first bloom of the uninfested plants, 36.1 days). For this latter situation, where economic losses have already been documented (Table 3.5), the delay associated with a specified DE loss can be determined.

Table 3.6. Regression equations for potato leafhopper density (number per m^2 and per stem) versus days past first bloom for alfalfa infested early (day 1) and late (day 14). Slopes (with standard errors denoted parenthetically) forced through the origin after determining that the Y-intercept term was not significantly different from zero. All regression coefficients are highly significant (*P*=0.01)

Infestation Period	Equation (SE)	Correlation
Early n=12	Delay = 0.106 x (PLH per m^2) (0.021)	0.87
	Delay = 64.34 x (PLH per stem) (12.68)	0.87
Late n=12	Delay = 0.037 x (PLH per m^2) (0.006)	0.91
	Delay = 21.07 x (PLH per stem) (3.47)	0.90
Overall n=24	Delay = 0.059 x (PLH per m^2) (0.012)	0.77
	Delay = 33.69 x (PLH per stem) (6.99)	0.76

With a known delay period, the EIL expressed in PLH density can be determined with the relationship depicted in the small graph of Fig. 3.2.

Economic-injury level calculations for an array of market value and control cost situations are provided in Table 3.7. The procedure for calculating the economic-injury levels involved an initial calculation of gain thresholds (Stone and Pedigo 1972) to determine the break-even point in nutrient yields. For example, with control costs of \$17.30/ha and

Figure 3.2. Stylized graph representing the delayed development and maturity response of alfalfa energy yield (Mcal) subjected to two densities of potato leafhopper (0 and 200 adults/m^2). Economic-injury level calculations for alfalfa harvested on a calendar-date basis are also indicated (smaller graph), with visual representation of time and yield losses for a first-bloom harvest system

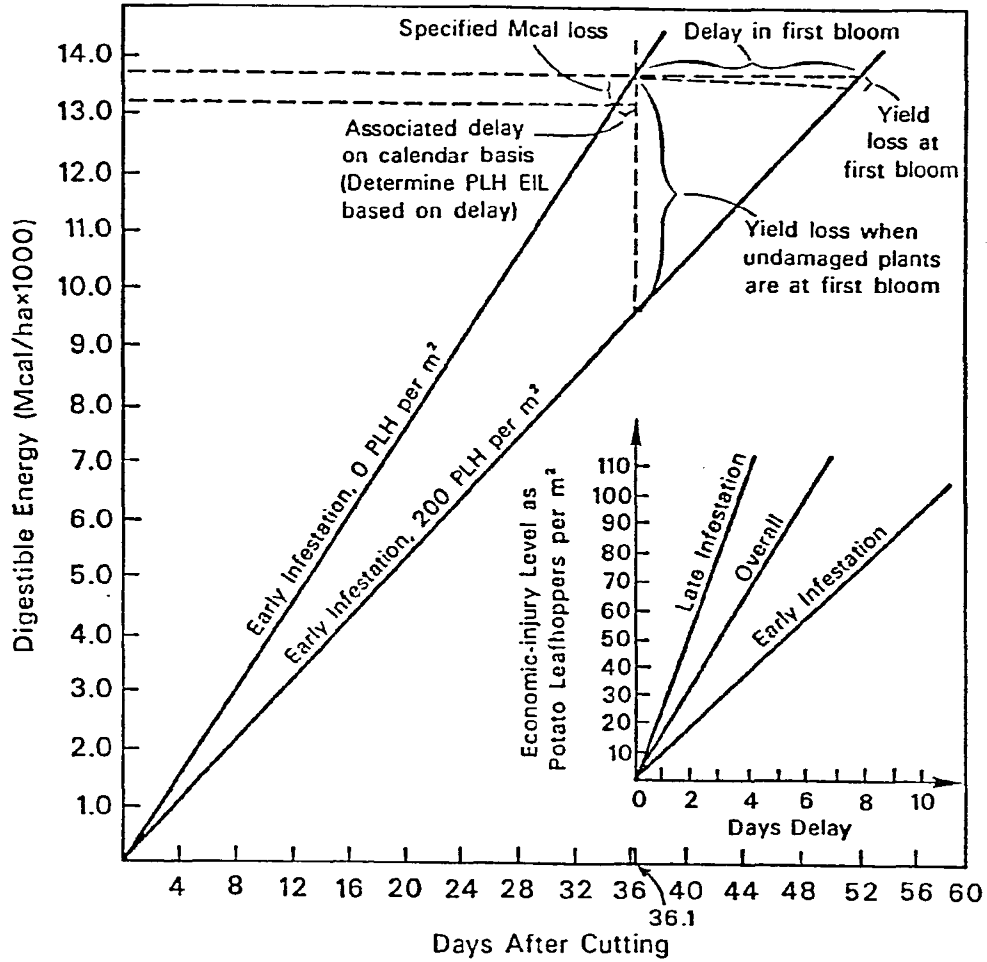

Specified Mcal loss
Delay in first bloom
Yield loss at first bloom
Associated delay on calendar basis (Determine PLH EIL based on delay)
Yield loss when undamaged plants are at first bloom
Early Infestation, 0 PLH per m²
Early Infestation, 200 PLH per m²
Digestible Energy (Mcal/ha×1000)
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
36.1
Days After Cutting
Economic-injury Level as Potato Leafhoppers per m²
110
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
Days Delay
Late Infestation
Overall
Early Infestation

Table 3.7. Economic time-delay equivalents (days) and economic-injury levels (EILs) for potato leafhopper (PLH per m^2 land) on alfalfa harvested on a calendar-date basis. Values for EILs of digestible energy and crude protein are based on costs of soybean meal (SBM) at two market prices. Values for EILs of dry matter are based on equivalent hay prices. Values are presented for early and late infestations (ca. 2 weeks after cutting) and overall. Ames, IA

		Management Costs = $17.30/ha		Management Costs = $24.70/ha	
Market Comparison	Infest Period	Time delay (days)	EIL	Time delay (days)	EIL
		Digestible Energy Basis			
SBM @ $0.193/kg	Early	0.85	7.23	1.21	11.39
	Late	0.88	23.73	1.25	33.89
	Overall	0.86	14.60	1.23	20.85
SBM @ $0.248/kg	Early	0.65	6.16	0.93	8.79
	Late	0.68	18.31	0.97	26.14
	Overall	0.66	11.27	0.95	16.09
		Crude Protein Basis			
SBM @ $0.193/kg	Early	1.49	14.09	2.13	20.12
	Late	1.50	40.58	2.14	57.94
	Overall	1.50	25.38	2.14	36.24
SBM @ $0.248/kg	Early	1.16	10.96	1.66	15.65
	Late	1.17	31.57	1.67	45.08
	Overall	1.16	19.75	1.66	28.19
		Dry Matter Basis			
HAY @ $0.061/kg	Early	2.19	20.64	3.12	29.48
	Late	2.28	61.76	3.26	88.17
	Overall	2.24	37.89	3.19	54.10
HAY @ $0.077/kg	Early	1.73	16.36	2.48	23.35
	Late	1.81	48.92	2.58	69.85
	Overall	1.77	30.02	2.53	42.86

soybean meal prices of $0.193/kg, a loss equalling 89.64 kg/ha of soybean meal (i.e., gain threshold = management costs/market value) is necessary to justify control. Inasmuch as the equivalency price reflects a nutrient substitution, the 89.64 kg of soybean meal is equivalent to ca. 320 Mcal of digestible energy (3.56 Mcal of DE/kg of soybean meal;

National Research Council 1978a). The next step for economic-injury calculation involves the determination of the delay period associated with the gain threshold. This is the gain threshold divided by the slope of the development line of DE (378.76 Mcal/day, Table 3.1) for uninfested plants. Hence, for the above example, a period of ca. 0.85 days (rounded) is an economic delay under the stated circumstances. Finally, the PLH infestation necessary to cause this delay period can be determined with the regression equations provided in Table 3.6 by dividing the delay period by the slope of the appropriate equation. For this example, the density of PLH which results in an economic-delay is ca. 7 per m^2.

The concept of managing a forage for its nutritional value, rather than its biomass per se, provides useful information regarding the relative utility of the feed. For example, the economic-injury levels for digestible energy are lower than those for crude protein, and considerably lower than for dry matter. Differences also exist among the early and late infested situations due to the altered slopes of development noted in Tables 3.1 and 3.6. Another factor which is often overlooked when presenting economic-injury levels is the vast difference that the market substitution prices and management costs play in the final determinations. Care should be taken to make accurate estimations of the relative value of the alfalfa if economic decisions are to be valid. Also, these calculations apply only to an intense calendar-date harvest system designed for optimal production. Alfalfa grown for less demanding applications, or harvested on a first bloom basis, would have much higher economic-injury levels. Continued delay, however, may have unpredictable results on the number of annual harvests or the persistence of the stand over a period of several years.

PART IV. ESTABLISHING ECONOMIC-INJURY LEVELS FOR FORAGES UTILIZED IN LEAST-COST RATIONING FOR LIVESTOCK PRODUCTION SYSTEMS

ABSTRACT

Forage pest management has been less amenable to the use of economic-injury levels (EILs) as decision guides than have cash crops. The primary reason for this incompatibility is the lack of a common exchange market for forages. In addition, the utilization of forages in various animal production systems varies so that the relative value of forages to other feeds depends on its contribution to the total ration. Least-cost rationing with linear programming provides a way of estimating the utility of forages in a ration, and provides a monetary value for the nutrients within the forage. The estimates of forage value can be used to calculate EILs based on final utilization of the forage to animal production. The technique is a refinement of current EIL calculations because differences in animal utilization are accounted for, *a priori*, in the pest management system.

Least-cost rations were calculated using data for feed nutrition and animal requirements. Animal production systems included three types of dairy cows, beef cows and steers, sheep, and horses. The objective was to determine the relative value of alfalfa to the total feed ration for each animal class and design a forage pest management system for the target animal. Least-cost rations chosen from six possible feeds determined the value of alfalfa, and these data were used in the calculation of EILs for potato leafhopper, *Empoasca fabae* (Harris), for each production system. Results demonstrate that horse and sheep production have the lowest EIL, while beef steers have the highest. The

magnitude of difference was 129% between the two, with dairy and beef producing cows having intermediate levels. The magnitude of difference in the EILs demonstrates the need to refine forage EILs based on the utility of the crop to the final utility of the animal consumer. Least-cost rationing provides one way of accomplishing this refinement.

INTRODUCTION

The integrated control concept was originally proposed as a means of reducing pesticide inputs while maintaining or increasing physical yields (Stern et al. 1959). These early concepts emphasized the economic advantage of monitoring pest populations and applying controls on an "as needed" basis. For implementation of the concepts, the authors proposed economic concepts in the form of the economic-injury level (EIL) and the economic threshold (ET). The integrated control concept was embraced by the scientific community and soon became the justification for expanding the concepts of insect management to include other pests (e.g., weeds and diseases) within an integrated pest management framework. However, a clear definition of the important variables associated with the EIL was lacking until 1972 (Stone and Pedigo 1972). The primary and secondary variables required to calculate an EIL were further elucidated in 1986 (Pedigo et al. 1986), along with research elements required to modify or refine EILs.

In its simplest form, an EIL has four components, two of which are biological variables and two are economic variables. The biological variables represent the injury potential of a pest and the host response to pest-induced injury. The two economic variables necessary to calculate an EIL are cost of control per unit of land area and market value per unit of yield. The model incorporating biological and economic variables is as follows (after Pedigo et al. 1986):

$$EIL = \frac{C}{V \times I \times D} \qquad \text{Equation 1.}$$

where, EIL = economic-injury level (insects/hectare); C = control costs ($/hectare); V = market value ($/unit of yield); I = unit of injury/insect; and, D = yield loss/unit of injury.

REFINEMENTS OF THE EIL

Of the four primary components of the EIL, most entomological research is centered around the two biological variables. Indeed, identifying the mode of host injury by a pest and quantifying its incremental injuriousness is paramount to developing useful pest management programs. Interdisciplinary research and increasing knowledge about pest biology and dynamics has led to numerous refinements in EILs. Generally, these refinements are the result of a greater understanding of host response to insect feeding under an array of environmental conditions. As research and knowledge continue to grow, the status of some EILs may change in category or application (Poston et al. 1983). Less work, however, has been conducted to refine the estimates for the economic variables. The basis for this has been a general satisfaction with the accuracy of estimating control costs and market value. Indeed, for most situations a telephone survey of control costs and a determination of the current exchange value will suffice. However, in cases where the commodity is not traded in large markets or is grown for on-farm use (e.g., forages), a market value is, at best, a rough estimate.

Estimating the Utility of Forages

As agricultural commodities, forages are unique. The fact that forages have poorly defined exchange markets and are commonly grown as an input for on-farm livestock production severely complicates traditional pest-management decision-making algorithms. The primary reason for this complication is the difficulty associated with assigning a dollar value which describes the utility of the crop to the consuming animal.

Management of feed inputs Forages are indispensable as feeds for livestock. Although grain crops will, on average, provide a higher rate of weight gain per day, the fiber provided by forages is necessary to maintain the microbial flora in the rumen and hence the health of the animal. Forages should not be totally eliminated in animal rations but should be utilized as a source of protein, energy, and fiber within a least-cost rationing strategy. Therefore, the value of alfalfa from one application to another will vary in relation to its proportionate contribution to the final formulated feed.

As an input, specific properties of a forage may be emphasized for some enterprises and less emphasized for others. For example, dairy producers commonly use alfalfa, *Medicago sativa* L., as a source of energy and protein to capitalize on its nutritional value, but beef producers are attracted to the high yields that alfalfa generates over several harvests. Both types of production require sufficient quality and quantity, but these may differ in degrees of importance.

As a business goal, the input costs of producing any commodity should be minimized to the degree that they do not constrain production. One method frequently employed to achieve these objectives is least-cost rationing with linear programming. This technique, which has the objective of minimizing the cost of a feed ration while maintaining optimal animal growth rates, has proved helpful as a management tool to reduce input costs in animal production systems. In addition to providing the optimal mix of available feeds, linear programming provides a wealth of data on production efficiency. For example, income penalties for using a non-optimal mix of feeds, and the value of the last unit of a nutrient (i.e., value marginal product), are calculated and utilized for planning. For pest management purposes, these data can be used as a relative measure of feed utility and utilized to calculate EILs for forage crops.

A least-cost rationing example To evaluate the potential value of least-cost rationing to forage pest management, linear programming models were constructed to calculate optimal rations for an array of animal production systems. The models were constructed with the objective of minimizing feed costs while satisfying required energy, protein, and nutrient requirements. The general form of the models were:

MINIMIZE: $$z = \sum_{i=1}^{n} C_i \cdot F_i$$

SUBJECT TO:

(1) $$\sum_{i} DE_i \cdot F_i \geq DE_r$$ Digestible Energy (Mcal)

(2) $$\sum_{i} CP_i \cdot F_i \geq CP_r$$ Crude Protein (g)

(3) $$\sum_{i} Ca_i \cdot F_i \geq Ca_r$$ Calcium (g)

(4) $$\sum_{i} P_i \cdot F_i \geq P_r$$ Phosphorous (g)

(5) $\sum_{i} DM_i \bullet F_i \leq DM_r$ Dry Matter (kg)

(6) $F_i \geq 0$ Non-negativity Constraint

The objective function states that the model will minimize the total cost of feeds (denoted as $\underline{z}$). The solution is constrained by minimum or maximum requirements of required nutrients. Digestible energy (DE), crude protein (CP), calcium (Ca), and phosphorous (P) for each available feed (i) must have a minimum level of consumption denoted as DE_r, CP_r, Ca_r, and P_i, respectively. Dry matter intake for each feed (DM_i), however, must not exceed a maximum level of intake (DM_r).

Available feeds for the least-cost rationing model are presented in Table 4.1. Nutrient compositions for individual feeds were based on National Research Council (1978a) estimates and were used for all animal production systems (denoted as DE_i, CP_i, Ca_i, P_i, or DM_i, where $\underline{i}$ is the specific feed). Prices for each of the purchased feeds were based on central Iowa market prices for July, 1987. The market prices are denoted as C_i in the linear programming model.

Nutrient requirements for various types of dairy and beef producing cattle are presented in Table 4.2. Data for dairy production included requirements necessary for a 750-kg Holstein cow producing 35 kg of fat corrected milk (FCM), a 600-kg Jersey cow producing 25 kg of FCM, and a 250-kg Heifer gaining 0.50 kg/day. Data for beef production included requirements for a 550-kg cow (in middle third of pregnancy) and a 250-kg steer gaining 1.0-kg/day.

Table 4.1. Nutrient compositions of digestible energy (DE, Mcal/kg), crude protein (CP, g/kg), calcium (Ca, g/kg), phosphorous (P, g/kg), dry matter (DM, kg/kg) and cost ($) of six feeds available to the least-cost rationing model (National Research Council 1978a)

	Early-bloom sun-cured alfalfa hay (i=1)	Ground corn (i=2)	Corn[b] Silage well-eared (i=3)	Soybean meal (extract.) (i=4)	Dicalcium phosphate (i=5)	Oats (i=6)
DE_i	2.56	3.88	3.08	3.56	0.00	3.34
CP_i	172	100	80	496	0.00	136
Ca_i	12.50	0.30	2.70	3.60	237	0.70
P_i	2.30	3.10	2.00	7.50	188	3.90
DM_i	1.00	1.00	1.00	1.00	1.00	1.00
Cost	0.70[a]	0.13	0.06	0.19	0.11	0.13

[a]Price for alfalfa set arbitrarily high to exclude from the solution so the utility can be derived from income penalties.

[b]Corn silage not provided as an option for sheep and horses.

Nutrient requirements for sheep and horse production were also utilized to make comparisons among ruminant species (Table 4.3). Data on sheep production for an 80-kg ewe (non-lactating) and a 40-kg lamb gaining 0.275-kg/day were utilized to calculate least-cost rations. For horse rations, nutrient requirements for a 600-kg mature horse and a 385-kg yearling (gaining 0.60-kg/day) were utilized.

Table 4.2. Daily nutritional requirements or limits for digestible energy (DE_r, Mcal), crude protein (CP_r, g), calcium (Ca_r,g), phosphorous (P_r,g), and dry matter (DM_r,kg) for various dairy (National Research Council 1978a) and beef (National Research Council 1976) animal production systems

	Dairy 750-kg Holstein at 35-kg FCM[a]	600-kg Jersey at 25-kg FCM	250-kg Heifer at 0.5-kg gain/day
DE_r	72.6	54.8	16.5
CP_r	3612.0	2664.0	678.0
Ca_r	119.5	88.5	22.0
P_r	83.0	62.0	16.0
DM_r	23.3	18.0	6.3

	Beef 500-kg cow middle 1/3 of pregnancy	250-kg steer 1.0-kg gain/day
DE_r	20.4	20.7
CP_r	657.0	730.0
Ca_r	18.0	26.0
P_r	18.0	21.0
DM_r	9.5	6.0

[a]Fat corrected milk.

Table 4.3. Daily nutritional requirements or limits for digestible energy (DE_r, Mcal), crude protein (CP_r, g), calcium (Ca_r,g), phosphorous (P_r,g), and dry matter (DM_r,kg) for various sheep (National Research Council 1985) and horse (National Research Council 1978b) animal production systems

	Sheep	
	80-kg ewe non-lactating	40-kg lamb at 0.275-kg gain/day
DE_r	3.6	5.4
CP_r	139.0	185.0
Ca_r	3.8	6.6
P_r	3.3	3.3
DM_r	1.5	1.6

	Horses	
	600-kg horse mature	385-kg yearling 0.275-kg gain/day
DE_r	18.8	18.9
CP_r	730.0	900.0
Ca_r	27.0	35.0
P_r	17.0	25.0
DM_r	8.5	6.8

As an example, the complete listing of a linear programming model for a 750-kg Holstein producing 35-kg FCM is presented in Table 4.4. The objective function (line 1) requires that the total feed cost be minimized and includes the market prices for each feed. Constraint lines

2-6 specify the nutrient requirements and individual feed contributions to digestible energy, crude protein, calcium, phosphorous, and dry matter, respectively. For example, line 2 states that alfalfa, corn, corn silage, soybean meal, dicalcium phosphate, and oats contribute 2.56, 3.88, 3.08, 3.56, 0.00, and 3.34 Mcal/kg, respectively, toward the minimum requirement of digestible energy (72.6-kg/day). The complete listing of nutritional quality for all feeds is presented in Table 4.1. Constraint lines 7-12 require non-negativity in the solution.

Table 4.4. Example linear programming model to calculate least-cost rations for a 750-kg Holstein cow producing 35-kg of fat corrected milk. Model includes an objective function (line 1) and constraints

MINIMIZE:

1) $Z = 0.70(F1) + 0.13(F2) + 0.06(F3) + 0.19(F4) + 0.11(F5) + 0.13(F6)$

SUBJECT TO:

2) $2.56(F1) + 3.88(F2) + 3.08(F3) + 3.56(F4) + 0(F5) + 3.34(F6) \geq 72.6$

3) $172(F1) + 100(F2) + 80(F3) + 496(F4) + 0(F5) + 136(F6) \geq 3612.0$

4) $12.5(F1) + 0.3(F2) + 2.7(F3) + 3.6(F4) + 237(F5) + 0.7(F6) \geq 119.5$

5) $2.3(F1) + 3.1(F2) + 2.0(F3) + 7.5(F4) + 188(F5) + 3.9(F6) \geq 83.0$

6) $F1 + F2 + F3 + F4 + F5 + F6 \leq 23.3$

7) $F1 \geq 0$;

8) $F2 \geq 0$;

9) $F3 \geq 0$;

10) $F4 \geq 0$;

11) $F5 \geq 0$;

12) $F6 \geq 0$;

Solutions for least-cost rationing models provide information on the overall production system and the individual feeds used in the rations.

A dollar value on the minimum cost of a ration which meets the established production criteria is of primary importance. In addition, the value marginal product for each nutrient is provided which furnishes information on the value of the last unit of that nutrient. Because the objective of these models was to estimate the cumulative value of on-farm forages, the programming strategy was to determine the value of all utilized nutrients in alfalfa based on its relative contribution to the total feed ration. To determine the on-farm value of alfalfa, an artificially high market price was used (i.e., $0.70/kg) in the model to insure that alfalfa was not selected in the final ration. The monetary value of alfalfa, then, represents the artificial market value minus the income penalty for forcing alfalfa into the solution. Income penalties are provided in the solution report for linear programming and represent the monetary loss associated with using a unit of a suboptimal feed. In addition, for this example an income penalty also represents the sum of the value of individual nutrients. Table 4.5 provides the calculated value of alfalfa for each of the example animal production systems under investigation.

Using Feed Ration Data for Pest Management

With the establishment of monetary values for the utility of alfalfa in each production system, the calculation of realistic EILs for forage pests can proceed. The potato leafhopper, Empoasca fabae (Harris), has long been identified as a serious pest of alfalfa (Osborn 1896). The primary mode of injury by this pest has been characterized as phenological delay in maturity, which results in a reduction of harvestable nutrient yield when harvested at regular intervals. In addition, PLH-induced injury has not been demonstrated to significantly alter the quality of alfalfa per unit of yield, so the primary loss is associated with dry matter reduction.

Table 4.5. Monetary value of alfalfa produced for various animal production systems as determined by least-cost models. Values were calculated as the difference of the artifically high market price minus the income penalty for forcing the alfalfa into the model

Animal production	Animal type	Alfalfa value ($) per kg dry matter
Dairy	750-kg Holstein at 35-kg FCM[a]	$0.086
	600-kg Jersey at 25-kg of FCM[a]	0.086
	250-kg Heifer at 0.50-kg gain/day	0.086
Beef	550-kg cow, middle 1/3 of pregnancy	$0.081
	250-kg steer at 1.00-kg gain/day	0.048
Sheep	80-kg ewe, non-lactating	$0.109
	40-kg lamb at 0.275-kg gain/day	0.109
Horses	600-kg horse, mature	$0.109
	385-kg yearling at 0.60-kg gain/day	0.109

[a]Fat corrected milk.

Values for EILs associated with PLH-induced injury to alfalfa grown for various animal production systems are presented in Table 4.6. Calculation of the EILs utilized a modification of the method described by Pedigo et al. (1986). Gain thresholds (Stone and Pedigo 1972) were determined based on two conceivable levels of management costs and the least-cost rationing determination for the monetary value of on-farm produced alfalfa. The phenological delay was determined by dividing the gain threshold by the rate of dry matter development over the season (determined in Part III to be 126.86 kg/day). The resulting value was the y-intercept of regression equations presented in Part III for predicting delay based on PLH density (equations forced through the origin). The EIL, then, was calculated by dividing the period of delay by the slope of the linear equations to determine PLH/m^2 and PLH/stem. For pests that directly consume forage yield, the gain threshold would be divided by the slope of the damage function (e.g., kg yield consumption/larva).

Table 4.6. Calculated economic-injury levels (EILs) for potato leafhopper (PLH) on alfalfa grown for various production systems. EILs are based on least-cost rationing estimates of alfalfa value and phenological delay response of the crop to PLH-induced injury

Animal Production	Pest Management costs = $17.30/ha		Pest Management costs = $24.70/ha	
	PLH/m^2	PLH/stem	PLH/m^2	PLH/stem
Dairy (all)	26.88	0.05	38.37	0.07
Beef cow	28.54	0.05	40.74	0.07
Beef steer	48.15	0.08	68.75	0.12
Sheep (all)	21.21	0.04	30.28	0.05
Horse (all)	21.21	0.04	30.28	0.05

Conclusions and Discussion

For the PLH example, the EIL was highest for alfalfa grown as feed for horses and sheep, and lowest for alfalfa grown for beef steers. Intermediate EILs were calculated for dairy producing cows and beef cows. The results demonstrate substantial differences in the EILs because the relative value of alfalfa to other feeds for each animal class varies. The analysis underscores the necessity of determining the final destination of a crop prior to developing a comprehensive pest management program.

Because forages are unique commodities and have poorly defined exchange markets, there is a need to view their value as total utility to the consuming animal. To this end, pest management programs should include EILs which based on animal utilization. These "customized" EILs provide a refined estimate of the worth of alfalfa produced for on-farm use. Further, they advance the overall implementation of pest management philosophy by integrating management decisions into the framework of the production system.

SUMMARY AND CONCLUSIONS

The physiological response of alfalfa to potato leafhopper (PLH) feeding was investigated in three field trials during 1984 and 1985. The specific objectives of the investigation were: (1) characterize the growth and development of the yield and yield components of alfalfa subjected to PLH feeding, (2) determine, with the assistance of crop growth analyses, the rates of crop development for injured and uninjured plants, (3) assess the impact of PLH-induced injury on the quality of alfalfa, with emphasis placed on the calculation and use of quality parameters predictive of animal growth, (4) establish the effect of PLH feeding on the role of alfalfa stems and leaves to the overall utility of the crop, (5) quantify the impact of PLH feeding on rate of development of alfalfa and model the nutrient yield development over time, and (6) modify the conceptual and practical means of estimating the value of forages grown for on-farm applications and use these estimates to refine the calculation of EILs.

Measurements of biomass yield and development allowed for an in-depth characterization of alfalfa growth subjected to PLH-induced stress. Stem density was not altered by PLH feeding, but stem height was significantly reduced at all infestation levels. The reductions in stem height were seen in plots infested one-day and fourteen-days following first harvest and first appeared within seven days after the initiation of feeding. The leaf component was generally affected less than the stem component. However, when leaf area values were adjusted to include only the non-chlorotic tissue, the leaf area index was significantly reduced for infested plots. Differences in individual leaf weights were not observed.

The overall biomass yield was reduced in the infested plots. Closer observation of individual crop, stem, and leaf growth rates indicated that the injured plants rapidly compensated for the initial injury before harvest. Measurements of net assimilation rate confirmed these observations. The results indicate that cutting early to reduce PLH losses may prevent the plant from compensating for early losses in biomass.

An investigation of the impact of PLH feeding on the quality parameters of alfalfa were conducted to characterize losses in nutritional value. Measurements for _in-vitro_ digestibility were not significantly different among the plots. The stem component was actually enhanced in digestibility by severe PLH feeding, but the leaf component was slightly less digestible. Similarly, the overall cell-wall concentration was largely unaffected by PLH-induced injury at harvest. Levels of crude protein were significantly altered by PLH feeding. Leaf proteins were reduced in most infested plots, but stem proteins were maintained or even enhanced with increasing levels of injury. Calculated measures for animal growth and utilization based on the chemical composition (digestible dry matter intake, relative feed value, and digestible energy) are presented for production reference. Results indicate that PLH should be managed more for its effect on biomass yield or nutritional yield per hectare rather than quality per se.

The rate of phenological development for PLH infested plots was significantly slower than uninfested plots. The atypical growth rates resulted in reduced rates of nutrient yield accumulations and increased the time necessary to reach reproductive maturity. An economic comparison demonstrated no differences in income among PLH densities when all plot yields were calculated at first bloom. However, plots evaluated on a calendar-date harvest system (e.g., cut every 26 days) produced less income as measured in replaceable nutrients. Rate of development was associated with final nutrient yield and PLH density was significantly correlated with phenological delay (measured in days). With the quantification of these two variables, and using local substitution prices for the value of alfalfa nutrients, economic-injury levels were calculated on a digestible energy, crude protein, and dry matter basis.

As a refinement to the application of EILs, a method of estimating the value of forages produced for on-farm use was presented. Least-cost rationing models for various animal production systems were constructed and utilized to calculate the relative value of alfalfa to the total ration. The simulation included actual nutrient requirements of one or more animal types for dairy, beef, sheep, and horse production. Results indicated that EILs for horse and sheep production are considerably higher (by a 52% margin) than EILs for dairy or beef production. The magnitude of the difference underscores the importance of identifying the value of a host before constructing pest management decision guidelines. For forages, where no clear exchange value exists, least-cost rationing may provide useful information on the relative value of the crop.

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APPENDIX A. COMPLETE VARIABLE LIST AND SAS PROGRAM LISTING USED FOR FIELD TRIALS (1984, 1985A & 1985B)

The intense insect and plant sampling for these studies resulted in a plethora of observed and calculated measurements. This Appendix is intended to serve as a reference for the variables used to determine the plant response to potato leafhopper feeding. Each variable is presented based on the plant component or type of variable in tabular form. Following this, the SAS program used to caluculate the variables is documented. The raw data are provided in Appendix B.

Variable Reference Guide

FORAGE:	
YLDP	YIELD/STEM (GM)
YLDM	YIELD/SQUARE METER (GM)
BIOMASS	YIELD (KG/HA)
HARVEST	DIRECT YIELD (KG/HA)
AVSTAGE	MORPHOLOGY (KALU AND FICK SYSTEM)
LESTRA	LEAF:STEM RATIO (GM/GM)
IVDDM	DIGESTIBLE DRY MATTER (%)
DDMYLD	DDM YIELD (KG/HA)
CP	CRUDE PROTEIN (%)
CPYLD	CRUDE PROTEIN YIELD (KG/HA)
NDF	CELL WALL CONCENTRATION (%)
NDFYLD	CELL WALL YIELD (KG/HA)
DMI	DRY MATTER INTAKE $(GM/W\ KG)^{.75}$
DDMI	DIGESTIBLE DRY MATTER INTAKE $(GM/W\ KG)^{.75}$
RFV	RELATIVE FEED VALUE
DE	DIGESTIBLE ENERGY (MCAL/KG OF FEED)
DEYLD	DIGESTIBLE ENERGY YIELD (MCAL/HA)
RSTHDEYD	RATIO STEM:LEAF DIGESTIBLE ENERGY YIELD
RSTHDDM	RATIO STEM:LEAF DIGEST DRY MATTER YIELD
RSTHCP	RATIO STEM:LEAF CRUDE PROTEIN YIELD
RSTHNDF	RATIO STEM:LEAF CELL WALL YIELD
RSTHDMI	RATIO STEM:LEAF DRY MATTER INTAKE
RSTHRFV	RATIO STEM:LEAF RELATIVE FEED VALUE
RSTHDE	RATIO STEM:LEAF DIGESTESTIBLE ENERGY
DDMST	DIGESTIBLE DRY MATTER/STEM (GM/STEM)
CPST	CRUDE PROTEIN/STEM (GM/STEM)
NDFST	CELL WALL/STEM (GM/STEM)

GROWTH ANALYSIS: (INSTANTANEOUS & OVERALL)

NAR	NET ASSSIMILATION RATE (MG/CM^2 OF LEAF/DAY)
RELGR	RELATIVE GROWTH RATE (MG/MG/DAY)
RELLAGR	RELATIVE LEAF AREA GROWTH RATE (CM^2/CM^2/DAY)
CGR	CROP GROWTH RATE (GM/M^2 OF LAND/DAY)
LGR	LEAF GROWTH RATE (GM/M^2 OF LAND/DAY)
DLGR	DAMAGED LEAF GROWTH RATE
HLGR	HEALTHY LEAF GROWTH RATE
SGR	STEM GROWTH RATE (GM/M^2 OF LAND/DAY)
LAGR	LEAF AREA GROWTH RATE (M^2/M^2 OF LAND/DAY)
LAAGR	ADJUSTED LEAF AREA GROWTH RATE
DLAGR	DAMAGED LEAF AREA GROWTH RATE (M^2/M^2 OF LAND/DAY)
HLAGR	HEALTHY LEAF AREA GROWTH RATE (M^2/M^2 OF LAND/DAY)
DAYHT	DAILY ACCUMULATION OF STEM HEIGHT (CM)
DAYNODES	DAILY ACCUMULATION OF NODES (NO.)
DAYTLEST	DAILY ACCUMULATION OF LEAVES/STEM
DAYDLEST	DAILY ACCUMULATION OF DAMAGED LEAVES/STEM
DAYHLEST	DAILY ACCUMULAITON OF HEALTHY LEAVES/STEM
DAYBIO	DAILY ACCUMULATION OF BIOMASS (KG/HA)
DAYROLN	DAILY ACCUMULATION OF ROOT LENGTH (CM)
DAYROWT	DAILY ACCUMULATION OF ROOT DRY WEIGHT (GM)
DAYNOWT	DAILY ACCUMULATION OF NODULE DRY WEIGHT (GM)
ONAR	NET ASSIMILATION RATE (MG/CM^2 OF LEAF/DAY)
ORELGR	RELATIVE GROWTH RATE (MG/MG/DAY)
ORELLAGR	RELATIVE LEAF AREA GROWTH RATE (CM^2/CM^2/DAY)
OCGR	CROP GROWTH RATE (GM/M^2 OF LAND/DAY)
OLGR	LEAF GROWTH RATE (GM/M^2 OF LAND/DAY)
ODLGR	DAMAGED LEAF GROWTH RATE
OHLGR	HEALTHY LEAF GROWTH RATE
OSGR	STEM GROWTH RATE (GM/M^2 OF LAND/DAY)
OLAGR	LEAF AREA GROWTH RATE (M^2/M^2 OF LAND/DAY)
OLAAGR	ADJUSTED LEAF AREA GROWTH RATE
ODLAGR	DAMAGED LEAF AREA GROWTH RATE (M^2/M^2 OF LAND/DAY)
OHLAGR	HEALTHY LEAF AREA GROWTH RATE (M^2/M^2 OF LAND/DAY)
ODAYHT	DAILY ACCUMULATION OF STEM HEIGHT (CM)
ODAYNODE	DAILY ACCUMULATION OF NODES (NO.)
ODAYTLEST	DAILY ACCUMULATION OF LEAVES/STEM
ODAYDLEST	DAILY ACCUMULATION OF DAMAGED LEAVES/STEM
ODAYHLES	DAILY ACCUMULATION OF HEALTHY LEAVES/STEM
ODAYBIO	DAILY ACCUMULATION OF BIOMASS (KG/HA)
ODAYROLN	DAILY ACCUMULATION OF ROOT LENGTH (CM)
ODAYROWT	DAILY ACCUMULATION OF ROOT DRY WEIGHT (GM)
ODAYNOWT	DAILY ACCUMULATION OF NODULE DRY WEIGHT (GM)

ROOT AND NODULES:

ROOTDW	DRY WEIGHT (GM/ROOT)
NODDW	DRY WEIGHT (GM/NODULE)
NODRT	NUMBER NODULES PER ROOT
RNASE	UMOLE C_2H_2/HR/ROOT (N FIX.)
NNASE	UMOLE C_2H_2/HR/NODULE (N FIX.)
NODWTRA	NODULE:ROOT RATIO (GM/GM)
ROSHRA	ROOT:SHOOT RATIO (GM/GM)

STEMS:

HT	STEM HEIGHT (CM)
NODES	NUMBER OF NODES PER STEM
NODLN	AVERAGE INTERNODAL DISTANCE (CM)
STDEN	STEM DENSITY (STEM/M^2)
STWT	STEM WEIGHT PER STEM (GM/STEM)
STWTM	STEM WEIGHT PER SQUARE METER (GM/M^2)
SIVDDM	STEM DIGESTIBLE DRY MATTER (%)
SDDMST	STEM DIGESTIBLE DRY MATTER PER STEM (GM/STEM)
SDDMYLD	STEM DIGESTIBLE DRY MATTER YIELD (KG/HA)
SCP	STEM CRUDE PROTEIN (%)
SCPST	STEM CRUDE PROTEIN PER STEM (GM/STEM)
SCPYLD	STEM CRUDE PROTEIN YIELD (KG/HA)
SNDF	STEM CELL WALL (%)
SNDFST	STEM CELL WALL PER STEM (GM/STEM)
SNDFYLD	STEM CELL WALL YIELD (KG/HA)
SDMI	STEM DRY MATTER INTAKE (GM/W KG)$^{.75}$
SDDMI	STEM DIGESTIBLE DRY MATTER INTAKE (GM/W KG)$^{.75}$
SRFV	STEM RELATIVE FEED VALUE
SDE	STEM DIGESTIBLE ENERGY (MCAL/KG FEED)
SDEYLD	STEM DIGESTIBLE ENERGY YIELD (MCAL/HA)
SGRADE	STEM GRADE

LEAVES: (TOTAL, HEALTHY, & DAMAGED):

TLEST	TOTAL LEAVES/STEM
HLEST	HEALTHY LEAVES/STEM
DLEST	DAMAGED LEAVES/STEM
TLEM	TOTAL LEAVES/M^2
HLEM	HEALTHY LEAVES/M^2
DLEM	DAMAGED LEAVES/M^2
TLAST	TOTAL LEAF AREA/STEM (CM^2)
TALAST	ADJUSTED TOTAL LEAF AREA/STEM
HLAST	HEALTHY LEAF AREA/STEM (CM^2)
DLAST	DAMAGED LEAF AREA/STEM (CM^2)
DALAST	ADJUSTED DAMAGED LEAF AREA/STEM
LAM	TOTAL LEAF AREA/M^2 (CM^2/M^2)
LAAM	ADJUSTED LEAF AREA /M^2
HLAM	HEALTHY LEAF AREA/M^2 (CM^2/M^2)
DLAM	DAMAGED LEAF AREA/M^2 (CM^2/M^2)
DALAM	ADJUSTED DAMAGED LEAF AREA/M^2
AVLALE	AVERAGE LEAF AREA/LEAF (CM^2/LEAF)
AVALALE	ADJUSTED AVERAGE LEAF AREA/LEAF
HLALE	HEALTHY LEAF AREA/LEAF (CM^2/LEAF)
DLALE	DAMAGED LEAF AREA/LEAF (CM^2/LEAF)
TLEWT	TOTAL LEAF WEIGHT (GM/STEM)
HLEWT	HEALTHY LEAF WEIGHT (GM/STEM)
DLEWT	DAMAGED LEAF WEIGHT (GM/STEM)
TLEWTM	TOTAL LEAF WEIGHT/M^2 (GM)
HLEWTM	HEALTHY LEAF WEIGHT/M^2 (GM)
DLEWTM	DAMAGED LEAF WEIGHT/M^2 (GM)
AVLEWTLE	AVERAGE LEAF WEIGHT/LEAF (MG)
HLEWTLE	AVERAGE LEAF WEIGHT/HEALTHY LEAF (MG)
DLEWTLE	AVERAGE LEAF WEIGHT/DAMAGED LEAF (MG)
SLW	SPECIFIC LEAF WEIGHT (MG/CM^2)
ASLW	ADJUSTED SPECIFIC LEAF WEIGHT
HSLW	HEALTHY SPECIFIC LEAF WEIGHT (MG/CM^2)
DSLW	DAMAGED SPECIFIC LEAF WEIGHT (MG/CM^2)
DASLW	ADJUSTED DAMAGED SPECIFIC LEAF WEIGHT
SLA	SPECIFIC LEAF AREA (CM^2/MG)
ASLA	ADJUSTED SPECIFIC LEAF AREA
HSLA	HEALTHY SPECIFIC LEAF AREA (MG/CM^2)
DSLA	DAMAGED SPECIFIC LEAF AREA (MG/CM^2)
DASLA	ADJUSTED DAMAGED SPECIFIC LEAF AREA
LWR	LEAF WEIGHT RATIO (GM LEAF/GM TOTAL)
HLWR	HEALTHY LEAF WEIGHT RATIO (GM LEAF/GM TOTAL)
DLWR	DAMAGED LEAF WEIGHT RATIO (GM LEAF/GM TOTAL)
LAR	LEAF AREA RATIO (CM^2/GM TOTAL)
ALAR	ADJUSTED LEAF AREA RATIO

HLAR	HEALTHY LEAF AREA RATIO (CM^2/GM TOTAL)
DLAR	DAMAGED LEAF AREA RATIO (CM^2/GM TOTAL)
DALAR	ADJUSTED DAMAGED LEAF AREA RATIO
LNR	LEAF NUMBER RATIO (NUMBER/GM)
HLNR	HEALTHY LEAF NUMBER RATIO (NUMBER/GM)
DAMAGED	DAMAGED LEAF NUMBER RATIO (NUMBER/GM)
PEHLAST	% HEALTHY LEAF AREA/STEM (CM^2)
PEDLAST	% DAMAGED LEAF AREA/STEM (CM^2)
PEDALAST	ADJUSTED PERCENT DAMAGED LEAR AREA/STEM
PEHEALE	% HEALTHY LEAF NUMBER
PEDAMLE	% DAMAGED LEAF NUMBER
HIVDDM	HEALTHY LEAF DIGESTIBLE DRY MATTER (%)
HDDMYLD	HEALTHY DIGESTIBLE DRY MATTER YIELD (KG/HA)
HDDMST	HEALTHY DIGESTIBLE DRY MATTER/STEM (GM/STEM)
HCP	HEALTHY LEAF CRUDE PROTEIN (%)
HCPYLD	HEALTHY LEAF CRUDE PROTEIN (KG/HA)
HCPST	HEALTHY LEAF CRUDE PROTEIN (GM/STEM)
HNDF	HEALTHY LEAF CELL WALL (%)
HNDFYLD	HEALTHY LEAF CELL WALL YIELD (KG/HA)
HDNFST	HEALTHY LEAF CELL WALL/STEM (GM)
HDMI	HEALTHY LEAF DRY MATTER INTAKE $(GM/W\ KG)^{.75}$
HDDMI	HEALTHY LEAF DIGESTIBLE DRY MATTER INTAKE $(GM/W\ KG)^{.75}$
HRFV	HEALTHY LEAF RELATIVE FEED VALUE
HGRADE	HEALTHY LEAF GRADE
HDE	HEALTHY LEAF DIGESTIBLE ENERGY (MCAL/KG FEED)
HDEYLD	HEALTHY LEAF DIGESTIBLE ENERGY YIELD (MCAL/KG FEED)
RDHLE	RATIO DAMAGED:HEALTHY LEAF NUMBER
RDHLA	RATIO DAMAGED:HEALTHY LEAF AREA
RADHLA	ADJUSTED RATIO DAMAGED:HEALTHY LEAF AREA
LAI	LEAF AREA INDEX (M^2/M^2)
ELAI	EFFECTIVE LEAF AREA INDEX (M^2/M^2)

SAS Program Listing

```
//C326 JOB
/*JOBPARM  L=90
//STEP1 EXEC SAS,TIME=2
//DS1 DD UNIT=DISK,DSN=L.I6435.FALL,DISP=SHR
//SYSIN  DD  *
DATA ISU;
INFILE DS1;
INPUT STUDY$ 1-2 YEAR 3-4 DATE 5 INFEST 6 DENS 7 TRT 6-7 BLK 8 HT 10-13 2
   EV 14-15 MV 16-17 LV 18-19 EB 20-21 LB 22-23 EF 24-25 LF 26-27 NODES
   28-31 2 TDAMLE 32-35 THEALE 36-39 TDAMLA 40-45 2 THEALA 46-51 2 STPROC
   52-53 STDENX 54-56 TDLEWT 57-60 2 THLEWT 61-64 2 TSTWT 65-68 2 HARVEST
   69-73 2 ROOTLN 74-77 1 NOROOT 78-80 #2 TRNFWT 1-7 4 TNODFWT 8-12 4
   TROOTDW 13-18 4 TNODDW 19-23 4 NONOD 24-26 TPLH 27-29 TNASE 30-35
   IVDDM 36-39 1 DVACN 40-41 DVACA 42-43 SWEEN 44-45 SWEEA 46-47 CP 48-50
   1 NDF 51-53 1 SIVDDM 54-56 1 SCP 57-59 1 SNDF 60-62 1 HIVDDM 63-65 1
   HCP 66-68 1 HNDF 69-71 1 PAR 72-75 1;
IF YEAR = 84 THEN DO;
   IF DATE=1 THEN DO; DAYS=10; NEWDAYS=10-0; END;
   IF DATE=2 THEN DO; DAYS=17; NEWDAYS=17-10; END;
   IF DATE=3 THEN DO; DAYS=24; NEWDAYS=24-17; END;
   IF DATE=4 THEN DO; DAYS=31; NEWDAYS=31-24; END;
   IF DATE=5 THEN DO; DAYS=38; NEWDAYS=38-31; END;
   IF DATE=6 THEN DO; DAYS=45; NEWDAYS=45-38; END;
   IF DATE=7 THEN DO; DAYS=40; NEWDAYS=40-0; END;
END;
IF YEAR = 85 THEN DO;
   IF DATE=1 THEN DO; DAYS=8;  NEWDAYS=8-0; END;
   IF DATE=2 THEN DO; DAYS=14; NEWDAYS=14-8; END;
   IF DATE=3 THEN DO; DAYS=22; NEWDAYS=22-14; END;
   IF DATE=4 THEN DO; DAYS=29; NEWDAYS=29-22; END;
   IF DATE=5 THEN DO; DAYS=35; NEWDAYS=35-29; END;
   IF DATE=6 THEN DO; DAYS=42; NEWDAYS=42-35; END;
END;
IF YEAR = 86 THEN DO;
   IF DATE=1 THEN DO; DAYS=7;  NEWDAYS=7-0; END;
   IF DATE=2 THEN DO; DAYS=14; NEWDAYS=14-7; END;
   IF DATE=3 THEN DO; DAYS=21; NEWDAYS=21-14; END;
   IF DATE=4 THEN DO; DAYS=28; NEWDAYS=28-21; END;
   IF DATE=5 THEN DO; DAYS=35; NEWDAYS=35-28; END;
   IF DATE=6 THEN DO; DAYS=42; NEWDAYS=42-35; END;
END;
*;
*****************************************************************;
*STEM DENSITY CALCULATIONS;
*****************************************************************;
*;
STDEN=STDENX*8.0;
```

```
NODLN=HT/NODES;
*****************************************************************;
*MORPHOLOGICAL STAGE AND PHENOLOGY DEVELOPMENT ANALYSES;
*****************************************************************;
*;
PEEV=EV/STPROC*100;
PEMV=MV/STPROC*100;
PELV=LV/STPROC*100;
PEEB=EB/STPROC*100;
PELB=LB/STPROC*100;
PEEF=EF/STPROC*100;
PELF=LF/STPROC*100;
AVSTAGE=((EV*0.0)+(MV*1.0)+(LV*2.0)+(EB*3.0)+(LB*4.0)+
   (EF*5.0)+(LF*6.0))/15.0;
*;
*****************************************************************;
*NUMBER OF HEALTHY AND DAMAGED LEAVES PER STEM AND PER AREA;
*****************************************************************;
*;
DLEST=TDAMLE/STPROC;
HLEST=THEALE/STPROC;
DLESTCM=DLEST/HT;
HLESTCM=HLEST/HT;
TLEST=DLEST+HLEST;
PEDAMLE=DLEST/TLEST*100;
PEHEALE=100-PEDAMLE;
TLEM=(DLEST+HLEST)*STDEN;
DLEM=DLEST*STDEN;
HLEM=HLEST*STDEN;
RDHLE=DLEM/HLEM;
*;
*********************************************************************;
*TOTAL, DAMAGED, AND HEALTHY LEAF AREA ANALYSES;
*********************************************************************;
*;
DLAST=TDAMLA/STPROC;
DALAST=(TDAMLA*00.32)/STPROC;
HLAST=THEALA/STPROC;
TLAST=DLAST+HLAST;
TALAST=HLAST+(DLAST*0.68);
PEDLAST=DLAST/TLAST*100;
PEDALAST=(DALAST/TLAST)*100;
PEHLAST=HLAST/TLAST*100;
AVLALE=TLAST/TLEST;
AVALALE=TALAST/TLEST;
IF DLEST=0 THEN DLALE=0; ELSE DLALE=DLAST/DLEST;
HLALE=HLAST/HLEST;
RDHLA=DLAST/HLAST;
RADHLA=DALAST/HLAST;
```

```
HLAM=HLAST*STDEN;
DLAM=DLAST*STDEN;
DALAM=DALAST*STDEN;
LAM=TLAST*STDEN;
LAAM=TALAST*STDEN;
LAI=LAM/10000.0;
ELAI=LAAM/10000.0;
*;
**********************************************************************;
*PLANT TOTAL AND COMPONENT WEIGHT ANALYSIS;
**********************************************************************;
*;
DLEWT=TDLEWT/STPROC;
HLEWT=THLEWT/STPROC;
TLEWT=DLEWT+HLEWT;
TLEWTM=TLEWT*STDEN;
DLEWTM=DLEWT*STDEN;
HLEWTM=HLEWT*STDEN;
STWT=TSTWT/STPROC;
STWTM=STWT*STDEN;
YLDP=DLEWT+HLEWT+STWT;
YLDM=YLDP*STDEN;
HLEWTLE=(HLEWT/HLEST)*1000.00;
IF DLEST=0 THEN DLEWTLE=0; ELSE DLEWTLE=(DLEWT/DLEST)*1000.00;
AVLEWTLE=(TLEWT/TLEST)*1000.00;
BIOMASS=YLDM*10.0;
BIOMASSE=BIOMASS*.000445;
*;
**********************************************************************;
*SPECIFIC LEAF WEIGHTS AND SPECIFIC LEAF AREAS;
**********************************************************************;
*;
IF DLALE=0 THEN DSLW=0; ELSE DSLW=DLEWTLE/DLALE;
IF DLALE=0 THEN DASLW=0; ELSE DASLW=DLEWTLE/(DLALE*0.32);
HSLW=HLEWTLE/HLALE;
SLW=AVLEWTLE/AVLALE;
ASLW=AVLEWTLE/AVALALE;
LESTRA=TLEWT/STWT;
IF DSLW=0 THEN DSLA=0; ELSE DSLA=1.0/DSLW;
IF DASLW=0 THEN DASLA=0; ELSE DASLA=1.0/DASLW;
HSLA=1.0/HSLW;
SLA=1.0/SLW;
ASLA=1.0/ASLW;
*;
**********************************************************************;
*LEAF WEIGHT, LEAF AREA, AND LEAF NUMBER RATIO ANALYSIS;
**********************************************************************;
*;
LWR=TLEWT/YLDP;
```

```
DLWR=DLEWT/YLDP;
HLWR=HLEWT/YLDP;
LAR=LWR*(SLA*1000.0);
ALAR=LWR*(ASLA*1000.0);
DLAR=DLWR*(DSLA*1000.0);
DALAR=DLWR*(DASLW*1000.0);
HLAR=HLWR*(HSLA*1000.0);
LNR=TLEST/YLDP;
DLNR=DLEST/YLDP;
HLNR=HLEST/YLDP;
*;
*************************************************************************;
*ROOT AND NODULE WEIGHT AND GROWTH ANALYSIS;
*************************************************************************;
*;
RNFWT=TRNFWT/NOROOT;
NODFWT=TNODFWT/NONOD;
ROOTDW=TROOTDW/NOROOT;
NODDW=TNODDW/NONOD;
IF NONOD=0 THEN NODRT=0; ELSE NODRT=NOROOT/NONOD;
RNASE=TNASE/NOROOT;
NNASE=RNASE/NODRT;
NODWTRA=NODDW/ROOTDW;
ROSHRA=ROOTDW/YLDP*NOROOT;
*;
*********************************************************************;
*POTATO LEAFHOPPER EFFECTS ON VARIOUS GROWTH PARAMETERS;
*********************************************************************;
*;
PLH=(TPLH+.0001)/9.0; PLH2=PLH**2;
CPLH=DVACN+DVACA+SWEEN+SWEEA; CPLH2=CPLH**2;
DVACPLH=DVACN+DVACA; DVACPLH2=DVACPLH**2;
SWEEPLH=SWEEN+SWEEA; SWEEPLH2=SWEEPLH**2;
*;
*******************************************************************;
*ALFALFA QUALITY ANALYSES;
*******************************************************************;
*;
DDMYLD=(IVDDM/100)*BIOMASS;
DDMST=(IVDDM/100)*YLDP;
CPYLD=(CP/100)*BIOMASS;
CPST=(CP/100)*YLDP;
NDFYLD=(NDF/100)*BIOMASS;
NDFST=(NDF/100)*YLDP;
SDDMYLD=(SIVDDM/100)*STWTM*10.0;
SDDMST=(SIVDDM/100)*STWT;
HDDMYLD=(HIVDDM/100)*HLEWTM*10.0;
HDDMST=(HIVDDM/100)*HLEWT;
SCPYLD=(SCP/100)*STWTM*10.0;
```

```
SCPST=(SCP/100)*STWT;
HCPYLD=(HCP/100)*HLEWTM*10.0;
HCPST=(HCP/100)*HLEWT;
SNDFYLD=(SNDF/100)*STWTM*10.0;
SNDFST=(SNDF/100)*STWT;
HNDFYLD=(HNDF/100)*HLEWTM*10.0;
HNDFST=(HNDF/100)*HLEWT;
DMI=146.9547+1.0137*NDF-00.00302*NDF**2;
SDMI=146.9547+1.0137*SNDF-0.0302*SNDF**2;
HDMI=146.9547+1.0137*HNDF-0.0302*HNDF**2;
DDMI=IVDDM*(DMI/100);
SDDMI=SIVDDM*(SDMI/100);
HDDMI=HIVDDM*(HDMI/100);
RFV=DDMI*1.4286;
SRFV=SDDMI*1.4286;
HRFV=HDDMI*1.4286;
IF RFV LT 90 THEN GRADE=5;
IF RFV GE 90 AND RFV LE 101 THEN GRADE=4;
IF RFV GE 102 AND RFV LE 119 THEN GRADE=3;
IF RFV GE 120 AND RFV LE 136 THEN GRADE=2;
IF RFV GE 137 THEN GRADE=1;
IF SRFV GT 0 THEN DO;
IF SRFV LT 90 THEN SGRADE=5;
IF SRFV GE 90 AND SRFV LE 101 THEN SGRADE=4;
IF SRFV GE 102 AND SRFV LE 119 THEN SGRADE=3;
IF SRFV GE 120 AND SRFV LE 136 THEN SGRADE=2;
IF SRFV GE 137 THEN SGRADE=1; END;
IF HRFV GT 0 THEN DO;
IF HRFV LT 90 THEN HGRADE=5;
IF HRFV GE 90 AND HRFV LE 101 THEN HGRADE=4;
IF HRFV GE 102 AND HRFV LE 119 THEN HGRADE=3;
IF HRFV GE 120 AND HRFV LE 136 THEN HGRADE=2;
IF HRFV GE 137 THEN HGRADE=1; END;
DE=-0.027+(0.0428*IVDDM);
DEYLD=DE*BIOMASS;
SDE=-0.027+(0.0428*SIVDDM);
SDEYLD=(STWTM*10.0)*SDE;
HDE=-0.027+(0.0428*HIVDDM);
HDEYLD=(HLEWTM*10.0)*HDE;
RSTHDDM=SDDMYLD/HDDMYLD;
RSTHCP=SCPYLD/HCPYLD;
RSTHNDF=SNDFYLD/HNDFYLD;
RSTHDMI=SDMI/HDMI;
RSTHDDMI=SDDMI/HDDMI;
RSTHRFV=SRFV/HRFV;
RSTHDE=SDE/HDE;
RSTHDEYD=SDEYLD/HDEYLD;
*;
*****************************************************************;
```

```
*CREATION OF LAG VARIABLES FOR GROWTH ANALYSES;
****************************************************************;
*;
PROC SORT DATA=ISU;
BY TRT BLK DATE;
DATA ISU;
SET ISU;
LYLDM=LAG(YLDM); LTLEWTM=LAG(TLEWTM); LDLEWTM=LAG(DLEWTM);
LHLEWTM=LAG(HLEWTM); LSTWTM=LAG(STWTM); LLAAM=LAG(LAAM);
LDALAM=LAG(DALAM); LLAM=LAG(LAM); LHLAM=LAG(HLAM); LYLDP=LAG(YLDP);
LTALAST=LAG(TALAST); LHT=LAG(HT); LNODES=LAG(NODES);
LTLEST=LAG(TLEST); LDLEST=LAG(DLEST); LHLEST=LAG(HLEST);
LBIOMASS=LAG(BIOMASS); LROOTLN=LAG(ROOTLN); LROOTDW=LAG(ROOTDW);
LNODDW=LAG(NODDW);
*;
****************************************************************;
*CROP AND PLANT GROWTH ANALYSES AND DAILY ACCUMULATION RATES;
****************************************************************;
*;
IF DATE=1 THEN NAR=((YLDM/LAAM)*(LOG(LAAM))*1000)/NEWDAYS;
ELSE NAR=(((YLDM-LYLDM)/(LAAM-LLAAM))*(LOG(LAAM)-
   LOG(LLAAM))*1000)/NEWDAYS;
IF DATE=1 THEN RELGR=(LOG(YLDM)*1000)/NEWDAYS;
ELSE RELGR=(LOG(YLDM)-LOG(LYLDM)*1000)/NEWDAYS;
IF DATE=1 THEN RELLAGR=(LOG(LAAM))/NEWDAYS;
ELSE RELLAGR=(LOG(LAAM)-LOG(LLAAM))/NEWDAYS;
CGR=(YLDM-LYLDM)/NEWDAYS;
LGR=(TLEWTM-LTLEWTM)/NEWDAYS;
DLGR=(DLEWTM-LDLEWTM)/NEWDAYS;
HLGR=(HLEWTM-LHLEWTM)/NEWDAYS;
SGR=(STWTM-LSTWTM)/NEWDAYS;
LAAGR=((LAAM/10000.0)-(LLAAM/10000.0))/NEWDAYS;
LAGR=((LAM/10000.0)-(LLAM/10000.0))/NEWDAYS;
DLAGR=((DALAM/10000.0)-(LDALAM/10000.0))/NEWDAYS;
HLAGR=((HLAM/10000.0)-(LHLAM/10000.0))/NEWDAYS;
DAYHT=(HT-LHT)/NEWDAYS;
DAYNODES=(NODES-LNODES)/NEWDAYS;
DAYTLEST=(TLEST-LTLEST)/NEWDAYS;
DAYDLEST=(DLEST-LDLEST)/NEWDAYS;
DAYHLEST=(HLEST-LHLEST)/NEWDAYS;
DAYBIO=(BIOMASS-LBIOMASS)/NEWDAYS;
DAYROLN=(ROOTLN-LROOTLN)/NEWDAYS;
DAYROWT=(ROOTDW-LROOTDW)/NEWDAYS;
DAYNOWT=(NODDW-LNODDW)/NEWDAYS;
IF NAR LT 0 THEN NAR=0;
IF RELGR LT 0 THEN RELGR=0;
IF RELLAGR LT 0 THEN RELLAGR=0;
IF LAAGR LT 0 THEN LAAGR=0;
IF CGR LT 0 THEN CGR=0; IF LGR LT 0 THEN LGR=0;
```

```
IF DLGR LT 0 THEN DLGR=0; IF HLGR LT 0 THEN HLGR=0;
IF SGR LT 0 THEN SGR=0; IF LAGR LT 0 THEN LAGR=0;
IF DLAGR LT 0 THEN DLAGR=0; IF HLAGR LT 0 THEN HLAGR=0;
IF DAYHT LT 0 THEN DAYHT=0; IF DAYNODES LT 0 THEN DAYNODES=0;
IF DAYTLEST LT 0 THEN DAYTLEST=0; IF DAYDLEST LT 0 THEN DAYDLEST=0;
IF DAYHLEST LT 0 THEN DAYHLEST=0; IF DAYBIO LT 0 THEN DAYBIO=0;
IF DAYROLN LT 0 THEN DAYROLN=0; IF DAYROWT LT 0 THEN DAYROWT=0;
IF DAYNOWT LT 0 THEN DAYNOWT=0;
IF DATE=6 THEN DO;
ONAR=((YLDM/LAAM)*(LOG(LAAM))*1000)/DAYS;
ORELGR=(LOG(YLDM)*1000)/DAYS;
ORELLAGR=(LOG(LAAM))/DAYS;
OCGR=YLDM/DAYS; OLGR=TLEWTM/DAYS; ODLGR=DLEWTM/DAYS;
OHLGR=HLEWTM/DAYS; OSGR=STWTM/DAYS; OLAAGR=LAAM/DAYS;
OLAGR=LAM/DAYS; ODLAGR=DALAM/DAYS; OHLAGR=HLAM/DAYS;
ODAYHT=HT/DAYS; ODAYNODE=NODES/DAYS; ODAYTLES=TLEST/DAYS;
ODAYDLES=DLEST/DAYS; ODAYHLES=HLEST/DAYS; ODAYBIO=BIOMASS/DAYS;
ODAYROLN=ROOTLN/DAYS; ODAYROWT=ROOTDW/DAYS; ODAYNOWT=NODDW/DAYS;
END;
***********************************************************************;
***********************************************************************;
//
```

APPENDIX B. RAW DATA FOR THREE FIELD TRIALS

(1984, 1985A & 1985B)

The following is a complete listing of the raw data collected during three field trials. The SAS program used to process these data are presented in Appendix A. The variable and column assignments can be found in the "Input" statement of the SAS program.

```
FS841111 126912 3 0 0 0 0 0 593    0 402      0 2003115 92   0  82  99
                            0        712         301505
FS841121 196910 5 0 0 0 0 0 620    6 354    390 2446515 96   2  91  58
                            3        784         326250
FS841131 1452 9 6 0 0 0 0 0 620   11 386    692 2905115 84   5 121  75
                            6        776         308394
FS841141 119612 3 0 0 0 0 0 650   18 387   1792 2183115163   6  79  62
                           11        774         283451
FS841211 125812 3 0 0 0 0 0 677    0 462      0 2932415115   0 136  93
                            0        731         297418
FS841221 122213 2 0 0 0 0 0 687    0 418      0 2325115105   0  96  67
                            0        753         299434
FS841231 1371 9 6 0 0 0 0 0 644    0 391      0 2495615102   0 105  84
                            0        740         301413
FS841241 120713 2 0 0 0 0 0 593    0 411      0 2131115166   0  89  81
                            0        689         252414
FS841112 1551 7 8 0 0 0 0 0 607    0 369      0 2900815114 104  99  86
                            0        771         328433
FS841122 144510 5 0 0 0 0 0 493   14 315    852 3111315118  04 101  86
                            2        767         324522
FS841132 093114 1 0 0 0 0 0 480   18 255   1729 1972815102  06  73  55
                            4        685         240512
FS841142 094715 0 0 0 0 0 0 467   34 221   2547 1573415 92  09  64  56
                           10        749         285501
FS841212 135110 5 0 0 0 0 0 547    0 381      0 3052615115   0 148 118
                            0        732         316502
FS841222 126313 2 0 0 0 0 0 587    0 372      0 2477115143   0 118  77
                            0        730         305513
FS841232 128113 2 0 0 0 0 0 620    0 348      0 2009815139   0 102  68
                            0        705         277436
FS841242 1369 8 7 0 0 0 0 0 573    0 363      0 2661715113   0 110  86
                            0        761         281427
FS841113 100715 0 0 0 0 0 0 580    0 301      0 1626115108  01  63  42
                            0        784         306457
FS841123 108115 0 0 0 0 0 0 573    4 293    298 1698615 80  01  69  51
                            1        754         301414
FS841133 1343 9 6 0 0 0 0 0 620    8 382    584 2458115 95  05  80  67
                            3        762         311384
FS841143 124611 4 0 0 0 0 0 613   10 355    768 2000315 82  02  80  50
                            5        746         284458
FS841213 132712 3 0 0 0 0 0 727    0 479      0 2685315 79   0 125  79
                            0        774         308448
FS841223 116513 2 0 0 0 0 0 707    0 468      0 2398615 90   0 118  68
                            0        765         324481
FS841233 106515 0 0 0 0 0 0 613    0 386      0 2426415 75   0 100  58
                            0        770         326466
FS841243 115815 0 0 0 0 0 0 667    0 456      0 1919815 94   0  96  51
                            0        735         294512
FS841114 1501 8 7 0 0 0 0 0 589    3 372    241 2448015107   0 100  84
                            0        765         299466
FS841124 100115 0 0 0 0 0 0 560   12 285    394 1740915 84  01  71  51
                            0        712         293412
FS841134 085515 0 0 0 0 0 0 420   17 216   1571 1664415 87  05  65  48
                            3        750         310532
FS841144 095115 0 0 0 0 0 0 513   27 213   1877 1392515 79  02  55  39
                            4        726         304495
FS841214 146810 5 0 0 0 0 0 647    1 393    159 2606815103  02 121  96
                            0        767         302491
FS841224 126512 3 0 0 0 0 0 613    0 365      0 2212215 97   0  89  84
                            0        783         343578
FS841234 095014 1 0 0 0 0 0 553    0 309      0 2083715118   0 100  39
                            0        772         331415
FS841244 125713 2 0 0 0 0 0 633    0 351      0 2154715116   0 104  71
                            0        758         295470
FS842111 1808 5 9 1 0 0 0 0 605    0 410      0 1642115 79   0  95  95
                            0        633         180494
FS842121 1520 5 9 1 0 0 0 0 615    0 455      0 2180415 91   0  97  97
                            3        658         180444
FS842131 1883 113 1 0 0 0 0 707    0 535      0 2111215 80   0 111 146
                            5        688         158460
```

FS842141	1349	9 6 0 0 0 0 0	720	1	447	134	1987315	100	01	97	116
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FS842211	1800	015 0 0 0 0 0	686	0	441	0	2494415	107	0	110	113
			0		642		190473				
FS842221	2178	310 2 0 0 0 0	847	0	657	0	3290015	108	0	174	191
			0		648		226504				
FS842231	2134	114 0 0 0 0 0	767	0	640	0	2605515	97	0	135	133
			0		665		202536				
FS842241	1871	510 0 0 0 0 0	693	0	465	0	2276515	89	0	105	114
			0		599		181510				
FS842112	2750	011 4 0 0 0 0	787	0	456	0	2868815	102	0	176	249
			0		755		255469				
FS842122	2133	015 0 0 0 0 0	720	0	435	0	3603215	92	0	192	165
			3		780		239533				
FS842132	1728	312 0 0 0 0 0	660	0	384	0	2065515	96	0	126	114
			8		744		254485				
FS842142	1673	6 9 0 0 0 0 0	680	3	320	306	1776915	91	02	119	101
			12		733		226456				
FS842212	2346	015 0 0 0 0 0	773	0	513	0	3319115	114	0	198	239
			0		739		269620				
FS842222	2489	014 2 0 0 0 0	760	0	591	0	4138815	114	0	208	210
			0		791		283561				
FS842232	2463	015 0 0 0 0 0	820	0	519	0	4064715	147	0	193	214
			0		775		303470				
FS842242	2340	015 0 0 0 0 0	767	0	555	0	3874815	119	0	190	184
			0		747		271480				
FS842113	2249	211 2 0 0 0 0	813	0	431	0	2874215	97	0	142	171
			0		595		193419				
FS842123	2137	211 2 0 0 0 0	680	0	390	0	2390115	98	0	122	143
			4		635		194384				
FS842133	1400	411 0 0 0 0 0	687	0	351	0	2286715	96	0	112	128
			8		624		322264				
FS842143	1952	213 0 0 0 0 0	713	4	409	349	2151815	95	02	102	104
			10		618		204360				
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			0		595		202326				
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			0		640		203562				
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			0		681		190390				
FS842243	2028	312 0 0 0 0 0	787	3	452	309	2465115	138	02	111	109
			0		657		232479				
FS842114	2377	014 1 0 0 0 0	753	0	489	0	3535315	99	0	164	162
			0		708		232381				
FS842124	1571	8 7 0 0 0 0 0	633	0	319	0	2191915	95	0	101	084
			0		766		269560				
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			1		703		235561				
FS842144	1407	11 4 0 0 0 0 0	607	3	382	428	2690215	91	02	135	103
			3		770		273456				
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			0		707		266439				
FS842224	2487	014 1 0 0 0 0	767	0	501	0	3404515	108	0	198	211
			0		758		265440				
FS842234	2271	015 0 0 0 0 0	707	0	456	0	3063915	116	0	214	217
			0		762		291518				
FS842244	1806	312 0 0 0 0 0	693	3	378	428	2480915	134	02	129	116
			0		715		238407				
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			0		724		207548				
FS843121	2487	011 3 1 0 0 0	760	13	574	1280	3155415	100	09	265	185
			1		756		195461				
FS843131	2569	012 3 0 0 0 0	767	27	624	2972	3194215	126	14	229	228
			2		755		219563				
FS843141	2159	311 1 0 0 0 0	867	55	629	5638	3345115	109	30	220	248
			0		734		185448				
FS843211	3341	0 5 9 1 0 0 0	973	0	973	0	5890215	85	0	274	254
			0		724		293527				
FS843221	3409	0 212 1 0 0 0	973	1	953	136	5766715	93	01	256	205
			1		736		251542				
FS843231	3035	0 5 7 2 1 0 0	860	3	917	162	5384215	103	02	219	209
			1		731		231575				
FS843241	1509	112 2 0 0 0 0	757	4	486	314	2430915	82	03	149	146
			1		752		212311				
FS843112	3235	0 4 6 4 1 0 0	960	5	937	1130	5513915	93	04	353	395
			0		698		217486				
FS843122	2247	014 0 1 0 0 0	780	39	621	3276	3363015	89	20	246	192
			2		734		211461				
FS843132	2357	3 8 3 1 0 0 0	813	67	503	7328	2721515	98	48	204	235

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                                  4        669          219458
FS843142 1836 8 6 1 0 0 0 0 667   86 346   8418 1790315 99   55 147 144
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FS843212 3816 0 013 2 0 0 0 973    11044    152 5659315 94   01 329 381
                            0        721          275609
FS843222 2522 013 1 1 0 0 0 867    2 772    314 4754715101   01 292 155
                            0        741          279579
FS843232 2811 0 9 4 2 0 0 0 860    4 733    601 4328415 99   01 266 237
                            1        719          266502
FS843242 2499 113 0 1 0 0 0 847    9 888    905 4003015102   02 249 207
                            2        725          246630
FS843113 2524 3 7 4 1 0 0 0 813    4 749    570 3947115108   01 190 232
                            0        692          250494
FS843123 2866 012 3 0 0 0 0 750   11 765    871 3313215104   02 194 206
                            2        714          197420
FS843133 2413 0 0 9 6 0 0 0 913   13 776   1097 3556715105   05 229 264
                            5        682          238485
FS843143 1857 510 0 0 0 0 0 773   45 498   4756 2079615117   28 134 127
                            8        724          207420
FS843213 3476 0 310 2 0 0 01000    0 984      0 5365415 71    0 268 302
                            0        711          275525
FS843223 3223 0 8 7 0 0 0 0 860    2 811    208 4947015100   01 207 195
                            1        708          224494
FS843233 2936 0 7 8 0 0 0 0 933    5 859    535 3698915113   03 221 203
                            2        716          235400
FS843243 2432 1 013 1 0 0 0 806    5 660    501 4274215105   03 184 150
                            3        710          248433
FS843114 2661 013 2 0 0 0 0 820    2 720    128 2831315 96   01 178 183
                            0        721          238459
FS843124 2294 410 1 0 0 0 0 693   22 653   3070 3882715 97   20 213 191
                            6        716          207501
FS843134 2183 212 1 0 0 0 0 773   51 705   6072 4193815106   35 237 207
                           10        709          199454
FS843144 2139 3 9 3 0 0 0 0 787   65 547   8608 3745715101   49 224 175
                           13        718          220466
FS843214 3649 0 114 0 0 0 0 933    01044      0 4650715105    0 256 308
                            0        745          266563
FS843224 3433 0 6 8 1 0 0 0 793    0 570      0 4762315 86    0 153 164
                            0        740          263552
FS843234 2969 0 311 1 0 0 0 773    0 738      0 5141015 78    0 213 264
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FS843244 2705 011 4 0 0 0 0 867    2 718    251 4453015 95   01 157 144
                            3        755          228535
FS844111 3449 0 4 9 2 0 0 0 987   23 958   3070 4337515105  15 235 379
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FS844121 2781 0 9 2 4 0 0 01027  140 904  15241 4253915 98 107 347 417
                            4        705          18039469016844579530 9621
FS844131 2607 113 0 1 0 0 01033  186 936  16905 3511615115 133 380 293
                            6        733          16643378117039479031 5533
FS844141 2158 213 0 0 0 0 01122  195 558  13982 2435115108 114 262 338
                           11        744          16746865218240281927 8314
FS844211 3721 0 2 9 4 0 0 01060    01071      0 7648015 91   0 370 337
                            0        701          22745868916343780236 5600
FS844221 3507 0 5 6 4 0 0 0 980    31194    382 6789315 77  01 333 183
                            4        719          22146571316144879334 8610
FS844231 3521 0 4 7 3 1 0 01020    51066    960 6633915106  01 323 377
                            9        724          20540369819036979435 3629
FS844241 2991 0 8 6 0 1 0 0 979   51 870   6909 4263815 80  38 288 362
                           11        714          19640968717643882034 4535
FS844112 3455 0 311 1 0 0 01133    01218      0 5889515 88   0 475 613
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FS844122 2997 0 8 6 1 0 0 01093  1171023  11586 4774915 85  82 417 393
                            1        746          18151469016844579530 9621
FS844132 2410 014 1 0 0 0 0 833   90 513  10463 3252515 86  59 232 248
                            4        654          17741178117039479031 5533
FS844142 1955 312 0 0 0 0 0 793   96 612   7632 3034615114  57 287 169
                            5        736          17539865218240281927 8314
FS844212 4087 0 010 3 2 0 01118    01141      0 7105015 87  01 246 257
                            0        732          26049568916343780236 5600
FS844222 2599 0 7 8 0 0 0 0 893    8 979    980 6292615112  08 283 267
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FS844242 2875 0 7 8 0 0 0 01067   36 912   3106 6458715106  24 298 179
                            5        703          21839268717643882034 4535
FS844113 3158 0 6 8 1 0 0 0 947    141025   1090 3962115 92  36 260 328
                            1        741          22854668016142380732 7664
FS844123 2806 011 3 1 0 0 0 920    901032  10130 4570915110  67 378 372
                           16        742          19031671214944080332 7563
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0 744 242501699171425808370607

FS844223 4207 0 111 1 2 0 01713 31401 204 7068415 95 02 384 510

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FS844114 3699 0 311 1 0 0 01160 291629 1196 7998315116 05 568 522

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FS844124 2728 014 1 0 0 0 01009 271077 4108 5050815 92 21 486 324

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FS844134 3158 0 5 9 0 0 1 0 967 601290 7615 6234415102 41 527 498

9 706 218420667174466816315577

FS844144 2228 014 1 0 0 0 0 880 105 672 11750 2977815 89 84 281 175

9 717 186358702178496793266544

FS844214 2945 0 015 0 0 0 0 947 0 741 0 4418115 73 00 269 161

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FS845121 2859 0 8 6 1 0 0 01087 1621335 13620 3454215 91 72 314 462

8 700 197407

FS845131 2951 0 8 7 0 0 0 0 987 1411290 14201 3994115 92 85 332 445

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1 656 193544

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FS845144 2253 011 1 2 1 0 0 913 585 387   91891  807715 92 297  73 302
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                                   4          687            194428
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FS846121 3193 010 4 0 0 0 11070     201884    1544 4685315 91  35 345 514 1760 122 11
 1098000013003890000103 14  2        0 647         23341861713833880121251 2
FS846131 2721 011 3 0 0 1 0 987     321056    2321 3554015 94  16 288 365 1458 109  9
 0852000015703080000119 30  3        0 649         172456623143320701188507
FS846141 2277 014 1 0 0 0 0 707     36 924    6625 3588015 77  45 138 306 1512 157  8
 1188000028503720000202 28  6        0 620         182362628140311805184534
FS846211 3404 0 5 4 0 3 2 11120      41059     409 3983815107  01 261 375 2317 140  8
 1032000015003850000125 14  0        0 677         204515631134435759296600
FS846221 3573 0 411 0 0 0 01050     111233    1427 4441015101  04 320 414 2650 111  7
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FS846241 3254 0 510 0 0 0 01147     251704    2751 3320915116  39 252 434 2345 124  8
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FS846112 4166 0 2 2 4 3 2 21253      02643       0 5306715 94   0 463 772 2358 136 10
 1104000026603980000171 52  0        0 674         186426607139357794257578
FS846122 3106 0 8 7 0 0 0 01060     361479    2969 4362515 95  14 339 403 2295 109  8
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FS863121	4343	0 015 0 0 0 0	707	0	792	0	7239515 52 0 363 554
			0		760		307284
FS863131	3398	0 411 0 0 0 0	607	4	651	715	5533815 80 007 254 345
			1		747		277449
FS863141	2792	0 7 7 1 0 0 0	553	3	594	395	4381115 65 001 225 269
			4		766		251394
FS863211	4055	0 1 8 2 2 1 1	792	01	149	0	8305515 45 0 429 610
			0		720		312382
FS863221	3935	0 411 0 0 0 0	653	4	786	887	7343715 69 003 344 498
			0		801		321529
FS863231	3181	0 5 6 4 0 0 0	607	4	681	598	4958015 72 005 238 287
			0		768		244469
FS863241	3123	0 6 9 0 0 0 0	593	5	792	661	5843915 73 010. 314 342
			0		735		285538
FS863112	4311	0 014 1 0 0 0	700	0	843	0	7440415 73 0 421 675
			0		758		215476
FS863122	3639	0 411 0 0 0 0	637	3	675	530	4800615 68 004 271 424
			0		755		241489
FS863132	3074	0 6 9 0 0 0 0	500	3	537	566	4559215 96 003 216 302
			0		763		280489
FS863142	2941	1 7 7 0 0 0 0	527	7	621	1568	6275115110 005 280 311
			2		768		290408
FS863212	4090	0 114 0 0 0 0	780	0	996	0	8466815105 0 445 596
			0		755		246465
FS863222	3437	0 410 1 0 0 0	629	4	783	840	7008415 75 003 322 365
			0		763		234427
FS863232	3513	0 5 8 2 0 0 0	713	4	867	656	7267815 78 001 401 438
			1		750		280456
FS863242	3267	0 5 7 3 0 0 0	733	6	729	1111	4323215 99 004 320 387
			1		770		282487
FS863113	4720	0 0 7 1 3 4 0	787	01	035	0	7621215 67 0 475 807
			0		810		300417
FS863123	2850	1 5 8 1 0 0 0	562	0	609	0	4573815 66 0 245 268
			0		720		249495
FS863133	3613	0 4 8 2 1 0 0	634	0	675	0	4068515 72 0 271 392
			1		737		203488
FS863143	2953	1 6 7 1 0 0 0	507	4	591	613	4701915 77 003 251 320
			0		752		274502
FS863213	3947	0 310 2 0 0 0	736	0	819	0	8523515 63 0 424 607
			0		763		282536
FS863223	3672	0 212 1 0 0 0	713	10	921	2106	8478815 44 009 424 530
			0		782		255418
FS863233	3353	0 5 7 3 0 0 0	620	9	804	1739	6657015 56 012 355 443
			0		780		245415
FS863243	3542	1 3 9 2 0 0 0	646	12	792	2200	6163115 65 016 403 472
			2		720		219454
FS863114	3864	0 013 2 0 0 0	673	2	831	272	6904715 97 001 420 564
			0		747		245414
FS863124	3506	0 4 9 2 0 0 0	609	6	876	828	6528015 83 003 347 454
			0		758		215439
FS863134	2683	0 4 9 2 0 0 0	572	8	759	1719	6844215 98 011 352 461
			0		760		257396
FS863144	2589	0 8 7 0 0 0 0	513	6	534	1017	4497515 76 004 239 299
			0		726		302532
FS863214	4629	0 114 0 0 0 0	753	0	840	0	8621415 84 000 430 703
			0		770		248360

FS863224 3092 2 3 9 1 0 0 0 540 0 651 0 5741715108 000 358 387
0 788 288571
FS863234 3211 0 1 9 5 0 0 0 613 3 783 616 5128315 98 004 358 375
0 765 261471
FS863244 3518 0 110 4 0 0 0 595 8 762 1371 5871815 93 004 379 450
1 774 311521
FS864111 4608 0 0 3 6 3 1 2 867 01320 0 10902815 66 000 384 676
0 743 30350263616831373032539
FS864121 3785 0 3 9 3 0 0 0 700 2 921 399 8200815 44 001 258 416
0 786 30152863916030574534056
FS864131 3901 0 411 0 0 0 0 707 6 849 774 6931315 59 002 271 399
0 737 25343365317532974033638
FS864141 3905 0 3 8 1 3 0 0 747 41020 661 6391415 59 002 247 400
2 724 26842258615338376734136
FS864211 5303 0 610 2 1 2 01019 21482 363 3453315 63 001 423 803
0 769 28249161915130168929756
FS864221 4220 0 3 8 3 1 0 0 736 9 936 1609 6994215 56 004 239 500
0 722 25247459217839672531646
FS864231 4444 0 112 1 1 0 0 673 7 867 1215 7753315 45 002 233 440
0 721 28247964314735071731951
FS864241 3504 0 5 9 1 0 0 0 567 14 819 2436 5598815 67 010 266 388
1 725 26950160118439373533536
FS864112 5273 0 0 8 3 2 0 2 962 41557 111110641515 74 002 429 987
0 730 29644260214933572030856
FS864122 3944 0 112 1 1 0 0 724 81086 1255 7182215 70 004 296 420
0 703 23144362415430874531034
FS864132 4525 0 112 2 0 0 0 813 7 990 796 6974315 88 005 278 515
0 715 23038265615334375036045
FS864142 3577 0 311 1 0 0 0 646 20 849 4040 7373615108 013 254 450
1 659 26543464819437474731649
FS864212 4989 0 013 1 1 0 0 953 21557 41910799515 96 001 473 800
0 740 27851964317440175930754
FS864222 4117 0 4 9 2 0 0 0 733 7 951 134410081615 79 004 279 498
0 692 23841860715740575331251
FS864232 3788 0 4 8 2 1 0 0 733 11 996 238610032915 78 011 331 483
1 723 22942570516843982630250
FS864242 3439 0 2 9 3 0 1 0 740 25 954 3978 6142415 90 017 289 416
0 665 27251563717839370531234
FS864113 5549 0 0 8 6 0 1 0 933 41753 81215891215 42 03 492 985
0 719 20139755513035372532739
FS864123 4074 0 111 1 2 0 0 800 31070 382 8796815 71 01 322 416
1 743 20941560013837070637150
FS864133 4539 0 1 9 1 2 2 0 867 111356 246310289915 73 05 355 607
0 723 28042160214530673330048
FS864143 3337 0 6 7 2 0 0 0 727 13 969 2141 8195115 53 05 256 340
1 697 22636763216339176130256
FS864213 5517 0 0 7 8 0 0 0 936 21452 32913747915 75 01 550 887
0 730 22638960317943272425758
FS864223 4387 0 310 2 0 0 0 800 51239 84515103615 44 03 441 631
0 683 26544064916141178434447
FS864233 3820 0 110 1 2 1 0 727 61164 1133 7785915 56 04 341 474
0 740 30343663816635978035339
FS864243 3322 0 6 7 1 1 0 0 660 43 699 10167 5971115 61 37 250 338
1 761 23241265418843877231447
FS864114 4467 0 0 5 6 2 2 0 840 31401 86910042115 99 02 460 649
0 739 24638460216634672535845
FS864124 3584 0 411 0 0 0 0 707 51029 1116 8188515 76 02 309 399
0 744 24643163415938878337838
FS864134 3739 0 310 1 1 0 0 747 7 903 1742 8249915 88 04 264 325
0 709 21142068217235377834944
FS864144 3595 0 6 9 0 0 0 0 665 6 942 1867 9252315 71 02 344 411
2 677 24642862217034776937055
FS864214 5700 0 010 2 3 0 0 833 21341 85617000315 85 04 542 962
0 715 23837062816137372437456
FS864224 3724 0 211 1 0 1 0 747 14 909 2298 6826815 92 07 261 370
0 694 26345963515038374031852
FS864234 3265 0 112 0 2 0 0 677 171086 2917 7385715 88 13 323 360
0 729 20945164714741081431354
FS864244 3104 2 310 0 0 0 0 700 49 864 9926 6590415 72 35 290 381
0 761 22043966616532878131454
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0 567 192285
FS865121 4967 0 0 6 9 0 0 0 920 151641 381213877715 51 08 398 815
0 637 234389
FS865131 5338 0 0 7 6 2 0 0 927 71569 181812502615 86 06 375 704
1 590 211314
FS865141 3983 0 1 9 5 0 0 0 827 221127 2739 7492915 53 06 242 330
3 551 225290
FS865211 5655 0 0 2 4 5 3 11057 82475 114513004415 45 03 5301193

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                                       0         622           252370
FS865221 5041 0 210 3 0 0 0 773    121020    2190 7195015 69    07 243 599
                                       1         624           255368
FS865231 4783 0 1 9 5 0 0 0 627    171029    2886 6798115 79    06 230 473
                                       1         634           219334
FS865241 3878 0 6 4 1 2 2 0 747    251056    3376 8532915 70    11 245 420
                                       2         578           209305
FS865112 4627 0 0 9 5 1 0 0 833     41506     945 9171115 67    01 433 630
                                       0         646           250365
FS865122 4516 0 0 6 2 5 2 0 787     52010     95311208115 69    04 538 692
                                       0         630           251400
FS865132 4376 0 0 311 1 0 0 817     71011    1024 6641515100    03 255 401
                                       1         665           219361
FS865142 5107 0 0 8 4 2 1 0 937    151494    347712096115 91    14 479 792
                                       0         664           240366
FS865212 4531 0 1 1 9 1 3 0 927     81500    1314 9295315107    03 448 675
                                       1         657           276397
FS865222 4127 0 1 8 3 3 0 0 780    111167    1771 7645115 85    05 328 480
                                       0         619           271414
FS865232 5107 0 1 3 5 6 0 0 900    321629    493810228615 67    24 499 880
                                       0         645           252367
FS865242 3686 0 1 7 3 4 0 0 833    181167    2167 6549715 87    07 327 458
                                       0         652           258390
FS865113 4680 0 0 6 0 5 0 4 960     01518    0   12803515 42    00 461 741
                                       0         641           266394
FS865123 4273 0 0 9 0 5 0 11013    111302    1707 9981415 72    04 343 461
                                       1         627           206383
FS865133 5171 0 0 4 2 8 0 11013    121740    1279 8711315 65    06 407 657
                                       1         660           263389
FS865143 4821 0 1 5 4 4 1 0 977    141650    293211993115 90    05 408 725
                                       0         628           232345
FS865213 5139 0 0 2 8 3 2 0 920     01935    0   11106715 76    00 466 789
                                       0         672           259351
FS865223 4137 0 6 7 0 2 0 0 800     91218    2271 9856315 34    09 366 706
                                       0         693           280442
FS865233 4362 0 2 7 5 2 0 0 933    241479    3848 8723415 68    14 365 531
                                       1         624           257388
FS865243 3859 0 4 5 3 2 1 0 820    451557    797814814815 60    32 445 632
                                       0         628           217383
FS865114 4505 0 4 2 5 3 1 0 767     61605     81211632815 66    05 474 650
                                       0         672           265383
FS865124 4930 0 0 4 6 5 0 0 827     81959    274915182215 67    07 558 770
                                       0         621           224347
FS865134 4659 0 3 5 5 2 0 0 693    161380    286310449115 76    11 365 680
                                       0         618           244376
FS865144 4283 0 3 5 1 4 2 0 677    161626    393011074415 79    10 488 720
                                       0         721           309507
FS865214 6074 0 0 6 4 3 0 0 877    9 951     1038 6531815 59    03 318 596
                                       0         648           264391
FS865224 4527 0 1 2 4 8 0 0 920    121386    293510099115 63    08 447 612
                                       1         648           217389
FS865234 3554 0 5 5 2 3 0 0 807     91173    1828 7534915 68    07 330 400
                                       1         636           280401
FS865244 4462 0 0 3 4 8 0 0 920    251740    582610796115 78    22 558 750
                                       3         651           231341
FS866111 5257 0 1 2 4 7 1 01027     02181     0  19672315 64 0    571 90928322 263   3
 442500        150900        1 0           636 254 0 82511975611453326622276542
FS866121 5875 0 0 3 012 0 01200     62334      75610487515 54   02 420 83829207 231   3
 266000         89700        0 2           648 451 5 92123915201293275882864l8
FS866131 5769 0 0 6 1 3 8 0 987     81914      72010077815 54   02 417 85931984 361   3
 329000        127900        2 1           628 046 0 52213495031413665843115 21
FS866141 4898 0 1 0 3 9 2 0 953    321839    2809 7783115 45    12 413 64524719 151   3
 066500         22500        0 1           666 23512 1211434536150223692311389
FS866211 6220 0 0 3 1 8 2 01029     81884     937 9992015 53    04 415 99029449 294   3
 364200        122800        4 2           659 553 2 52483525331573536453054 61
FS866221 5317 0 0 3 5 6 1 0 997    142349    18861094 7115 49   07 471 68629763 246   3
 291000        111900        0 2           654 645 1 72333784811542126533065 56
FS866231 5207 0 0 2 110 2 0 927    162334    12731015 3515 59   03 480 76929203 317   3
 411800        140500        2 2           644 761 1 42184435731471806613034 68
FS866241 4823 0 0 5 2 5 3 01020    421974    4351 8919615 46    16 422 83725960 308   3
 204000         76700        1 5           623 153 2 62394065841823496873265 17
FS866112 5054 0 1 3 3 3 3 01000     71830     821 8244315 67    02 426 68030940 201   3
 188500         69300        0 1           670 170 0 42103674971453356963384 70
FS866122 5150 0 1 6 3 6 0 0 927    141458    3425 8117215 74    12 316 63132131 257   3
 214200         67900        1 5           616 166 0 22243225421673016823304 53
FS866132 3871 0 4 1 2 7 1 0 877    241785    1848 7995815 60    07 384 56831696 285   3
 190200         62500        2 3           683 484 0 32593934941493066613345 34
FS866142 5420 0 0 5 3 6 1 0 880    111566    2106 8187215 73    06 381 70135624 345   3
 374000        120200        2 3           670 034 1 52404825601542837003215 42
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FS866212	5464	0 0 1 5 6	2 01086	362304	501612921915 56 17 513 90523004	218	3
346200	113100		1 1	672	112 0 2218411547146354667332461		
FS866222	4659	0 1 8 2 3	1 0 937	82013	103510382115 65 04 458 70034426	261	3
177000	49300		1 2	649	439 3 8245431530162370642334532		
FS866232	4881	0 3 5 1 4	2 0 967	341803	566211911015 59 18 437 81334570	398	3
254900	78800		13 1	665	444 1 3221337538149380622340451		
FS866242	5157	0 1 3 3 6	2 0 993	122244	106310097515 55 03 532 97025541	259	3
178500	57400		0 2	629	568 2 5223416547160310681330555		
FS866113	5881	0 0 0 411	0 0 957	42052	74512437215 59 01 592106928201	306	3
134500	44100		0 0	654	017 2 1207338502178349691307492		
FS866123	5677	0 0 1 112	1 0 987	02280	0 11918015 74 0 537 93332690	330	3
241000	85700		2 2	666	253 2 4262400498145333645263557		
FS866133	5346	0 0 2 3 7	1 1 867	61728	420 6713415 59 02 398 76831817	166	3
167200	51100		0 2	664	056 1 8212384514149355656288400		
FS866143	5350	0 0 4 2 8	1 0 927	141860	1275 9999315 77 16 334 63136332	241	3
219000	73000		0 2	672	177 2 7206346499148362622336528		
FS866213	5539	0 0 2 4 9	0 01013	131887	185612485815 65 02 524 98832756	216	3
289400	102100		4 0	640	052 1 4243321464150287666344526		
FS866223	5605	0 1 1 4 9	0 01020	252052	286010188515 48 05 509100324731	384	3
391200	124300		0 2	717	242 0 8264384517141377603317551		
FS866233	4585	0 1 5 1 8	0 0 927	231716	1963 7532215 54 09 374 60334476	273	3
203000	60300		0 2	631	054 4 8246323497139298674335411		
FS866243	4195	0 3 0 3 6	2 1 893	321467	3429 7532215 48 06 471 78829138	189	3
126000	33000		5 3	611	039 5 6211398511160286684328562		
FS866114	6908	0 0 0 211	1 11273	261977	488212403215 63 19 562132030652	342	3
358200	128800		2 0	638	573 0 4241253535166317656344446		
FS866124	5440	0 0 5 1 9	0 01200	361761	303010303315 60 14 555100031750	195	3
262000	88100		1 1	680	030 0 5240359544266275713338487		
FS866134	4253	0 5 3 3 2	2 01007	571308	6992 7598115 74 24 373 57735581	355	3
215000	82700		0 2	684	287 2122403805461583546993337484		
FS866144	6321	0 1 2 2 9	1 01114	151953	204912071115 58 09 561114033713	221	3
155000	51400		2 3	6381595	1 7200473549150310626340504		
FS866214	5225	0 0 2 1 8	4 01013	102154	180612486215 45 05 616105125599	298	3
543500	173700		11 0	664	360 2 7270200503153293571357493		
FS866224	4787	0 0 5 3 7	0 0 923	541983	581111567215 62 09 334 52429996	247	3
218000	74800		0 1	635	040 0 1208337526166365668339374		
FS866234	4304	0 0 5 3 5	2 0 880	51548	818 9403215 57 03 391 62628995	282	3
141500	49200		0 3	651	357 2 6225321480173343578365470		
FS866244	4084	0 2 4 2 5	2 0 883	181239	2428 7984815 69 22 501 83426000	220	3
199000	65100		4 3	688	035 2 3245312542156310683317387		

APPENDIX C. MEANS AND ANALYSIS FOR YIELD AND YIELD COMPONENT VARIABLES

Table C.1. Effect of various infestation periods and densities of potato leafhopper (PLH) on alfalfa stem density per m^2 at weekly sampling intervals for each of three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	842.0	754.0	784.0	802.0	756.0	694.0
	50	756.0	752.0	780.0	770.0	770.0	702.0
	100	736.0	756.0	870.0	764.0	688.0	702.0
	200	832.0	754.0	852.0	834.0	792.0	716.0
B	0	824.0	852.0	710.0	664.0	684.0	676.0
	50	870.0	874.0	760.0	720.0	692.0	738.0
	100	868.0	928.0	786.0	810.0	714.0	788.0
	200	978.0	960.0	768.0	732.0	744.0	818.0
LSD[a]		243.2	134.0	125.2	152.4	103.8	168.1
				1985A			
A	0	550.0	626.0	528.0	540.0	464.0	614.0
	50	560.0	548.0	544.0	500.0	496.0	538.0
	100	517.3	576.0	514.0	578.0	470.0	548.0
	200	610.7	576.0	518.0	572.0	524.0	560.0
B	0	604.0	590.0	592.0	630.0	486.0	592.0
	50	598.0	530.0	512.0	564.0	424.0	528.0
	100	654.4	646.0	616.0	686.0	590.0	614.0
	200	604.8	644.0	596.0	628.0	538.0	592.0
LSD[a]		133.8	144.8	93.0	108.8	99.6	117.7
				1985B			
A	0	438.0	580.0	644.0	562.0	516.0	506.0
	50	466.0	670.0	538.0	522.0	518.0	524.0
	100	518.0	714.0	692.0	616.0	654.0	494.0
	200	506.0	592.0	656.0	582.0	626.0	506.0
B	0	458.0	554.0	594.0	638.0	574.0	438.0
	50	430.0	536.0	592.0	542.0	502.0	448.0
	100	506.0	576.0	608.0	534.0	564.0	458.0
	200	486.0	570.0	660.0	580.0	590.0	436.0
LSD[a]		141.5	172.8	152.5	135.7	176.5	98.8

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.2. Effect of various infestation periods and densities of potato leafhopper (PLH) on alfalfa stem height (cm) at weekly sampling intervals for each of three field trials

Infest Period	PLH Density	Days after cutting: 7	14	21	28	35	Har
		1984					
A	0	13.32	22.96	29.73	34.40	34.97	34.74
	50	13.74	18.40	24.74	28.28	27.68	30.73
	100	11.45	16.60	23.81	27.87	27.04	28.31
	200	10.85	15.95	19.98	21.44	23.39	24.47
B	0	13.51	21.58	35.71	36.71	43.46	42.67
	50	12.29	22.62	31.47	37.45	40.61	39.59
	100	11.67	22.73	29.38	36.37	37.41	38.25
	200	12.48	20.11	22.86	33.13	29.48	31.47
LSD[a]		3.28	3.35	5.10	7.16	6.16	8.88
		1985A					
A	0	13.62	31.33	35.15	39.75	43.00	41.65
	50	11.39	25.08	26.41	29.15	32.06	32.71
	100	10.80	22.45	27.75	30.82	32.53	29.42
	200	10.07	22.91	27.40	29.31	31.59	29.97
B	0	12.40	24.51	32.88	36.33	39.94	41.75
	50	10.73	22.09	23.87	25.94	27.88	29.55
	100	11.98	23.70	25.61	27.65	31.47	29.32
	200	11.82	24.49	24.69	29.25	30.37	27.01
LSD[a]		2.37	2.71	6.14	6.87	5.93	6.56
		1985B					
A	0	16.69	31.52	42.03	49.74	47.50	57.75
	50	14.13	25.80	35.85	38.47	46.76	55.36
	100	11.93	25.70	31.92	41.76	48.86	48.10
	200	11.11	24.69	28.19	36.04	45.49	54.97
B	0	13.60	27.18	41.80	53.77	53.49	56.12
	50	14.04	24.16	35.34	41.12	44.58	50.92
	100	13.77	28.15	33.15	38.29	44.52	47.44
	200	13.10	26.94	33.63	33.42	39.71	45.65
LSD[a]		1.78	5.21	5.39	4.70	7.18	8.67

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.3. Effect of various infestation periods and densities of potato leafhopper (PLH) on effective leaf area index at weekly sampling intervals for each of three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	1.27	1.40	2.28	3.07	3.07	2.23
	50	1.20	1.30	1.85	2.75	2.46	1.98
	100	1.14	1.09	2.15	2.73	2.00	1.77
	200	1.10	1.09	1.81	2.19	2.27	1.67
B	0	1.56	1.82	2.54	3.04	3.55	2.58
	50	1.37	1.99	2.57	3.36	2.87	2.52
	100	1.28	1.98	2.42	3.73	2.83	2.47
	200	1.47	1.79	1.99	2.93	2.53	2.44
LSD[a]		0.48	0.52	0.68	1.13	0.93	0.63
				1985A			
A	0	0.61	1.82	1.97	2.26	2.47	3.91
	50	0.50	1.14	1.49	1.47	1.89	2.80
	100	0.40	1.17	1.33	1.90	2.00	1.90
	200	0.38	1.09	1.36	1.95	1.89	2.17
B	0	0.64	1.55	2.16	2.55	2.59	3.15
	50	0.48	1.15	1.30	1.51	1.47	1.95
	100	0.65	1.50	1.66	2.23	2.31	2.17
	200	0.59	1.48	1.57	1.80	1.93	1.71
LSD[a]		0.22	0.42	0.47	0.72	0.67	0.90
				1985B			
A	0	0.69	2.47	3.27	4.24	4.17	4.47
	50	0.55	1.91	2.07	2.83	4.38	3.60
	100	0.53	2.06	2.48	3.37	4.18	2.71
	200	0.50	1.79	2.27	3.09	4.70	3.27
B	0	0.65	2.10	3.37	4.99	3.77	3.55
	50	0.65	1.70	2.72	3.35	2.87	3.28
	100	0.64	2.07	2.42	3.01	3.19	3.04
	200	0.60	2.09	2.44	2.52	3.99	2.56
LSD[a]		0.29	0.75	0.91	1.36	1.86	1.34

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.4. Effect of various infestation periods and densities of potato leafhopper (PLH) on biomass yield (kg/ha) measured at weekly sampling intervals for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
		1984					
A	0	1076.5	1613.3	2756.1	4616.2	4792.4	4378.8
	50	760.6	1253.9	2261.3	4366.7	3737.1	3671.9
	100	736.8	1178.3	2801.8	4246.4	3558.8	3607.5
	200	723.2	1109.4	2234.6	3476.2	3661.1	2933.1
B	0	1274.6	1996.7	2818.7	2774.7	4364.7	3960.7
	50	1046.9	2152.2	2077.0	3259.0	3437.2	4292.0
	100	948.8	2154.8	2395.2	4292.4	3518.6	4834.4
	200	1126.5	1703.1	1803.0	2873.9	3556.4	3810.8
LSD[a]		349.7	542.6	690.7	1499.9	1195.0	1521.9
		1985A					
A	0	762.3	2226.9	2963.2	3515.3	3905.5	6485.3
	50	672.9	1438.9	2019.1	2221.8	2739.2	3951.4
	100	527.6	1256.4	2068.5	2773.0	2645.1	2758.3
	200	609.9	1198.8	2223.9	2797.5	2682.7	3052.4
B	0	872.2	1875.0	3315.7	3603.8	4072.3	5741.8
	50	721.4	1540.2	2085.8	2472.4	2176.7	3062.9
	100	920.0	1977.5	2479.5	3412.0	3604.2	3981.4
	200	840.4	1975.7	2348.5	2818.0	3075.6	3049.4
LSD[a]		287.3	409.7	824.9	1115.0	991.4	1469.0
		1985B					
A	0	854.2	2308.3	4751.9	4627.2	3815.7	5157.0
	50	688.2	1640.3	2610.7	2487.1	3933.8	4559.0
	100	646.3	1876.3	3026.5	3102.0	4120.2	3567.2
	200	622.6	1394.9	2441.7	2684.4	4616.1	4030.5
B	0	733.9	2009.4	4215.8	5808.5	4635.1	4382.5
	50	707.0	1629.0	3105.2	2790.7	3088.8	3455.1
	100	798.3	2140.6	2950.2	2691.2	3493.4	3467.5
	200	718.7	1950.0	3391.9	2645.7	3820.1	3467.5
LSD[a]		279.8	850.3	971.1	841.9	1698.9	1153.6

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.5. Effect of various infestation periods and densities of potato leafhopper (PLH) on the adjusted damaged leaf area (cm^2) per meter measured weekly for each of three field trials

Infest Period	PLH Density	7	14	21	28	35	Har
				Days after cutting			
				1984			
A	0	11.0	0.0	85.1	239.5	260.0	52.4
	50	83.2	0.0	344.7	1694.1	2531.0	478.5
	100	182.0	0.0	789.9	2038.1	3244.0	503.5
	200	314.7	48.4	1226.1	2264.0	6352.0	710.5
B	0	7.0	0.0	6.1	0.0	33.0	66.6
	50	0.0	0.0	27.8	96.4	554.0	198.1
	100	0.0	0.0	58.3	298.1	715.0	575.2
	200	0.0	42.7	83.0	674.1	1286.0	1999.7
LSD[a]		104.5	26.8	263.5	665.3	2794.2	1362.0
				1985A			
A	0	0.0	0.0	27.4	40.0	29.5	179.2
	50	0.0	6.1	176.0	583.5	319.3	232.8
	100	0.0	0.0	326.3	986.8	454.0	537.1
	200	0.0	25.3	554.9	1192.9	853.5	811.6
B	0	0.0	0.0	50.8	98.6	144.9	275.1
	50	0.0	0.0	223.8	251.3	235.9	524.3
	100	0.0	0.0	248.5	622.5	756.0	1440.0
	200	0.0	0.0	366.4	790.8	1266.6	2024.6
LSD[a]		0.0	26.2	172.3	410.3	460.5	575.0
				1985B			
A	0	0.0	0.0	20.8	86.3	79.9	173.5
	50	8.1	12.2	44.7	92.7	242.0	203.1
	100	31.0	66.2	119.5	191.5	238.7	295.2
	200	108.2	64.6	137.7	307.8	442.0	212.1
B	0	0.0	0.0	0.0	68.5	108.1	227.2
	50	0.0	0.0	92.5	189.8	240.5	280.4
	100	0.0	0.0	107.5	239.3	403.1	239.7
	200	0.0	0.0	182.9	791.9	579.4	252.0
LSD[a]		39.7	29.1	105.9	268.0	204.1	300.2

[a]LSD = least significant difference ($P = 0.05$).

Table C.6. Effect of various infestation periods and densities of potato leafhopper (PLH) on number of mainstem nodes measured at weekly sampling intervals for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	5.92	7.40	9.05	10.57	11.12	12.12
	50	5.62	6.62	7.46	10.12	10.40	10.99
	100	5.35	6.82	8.17	9.55	9.37	10.32
	200	5.61	6.80	7.74	9.26	9.59	8.99
B	0	6.50	7.53	9.70	10.53	11.13	11.43
	50	6.49	7.77	8.73	11.70	10.88	11.13
	100	6.08	7.72	8.57	11.29	10.82	11.57
	200	6.17	7.35	8.19	10.28	10.23	11.14
LSD[a]		0.68	0.77	0.96	2.39	1.31	1.39
				1985A			
A	0	5.87	6.35	7.17	9.31	9.43	10.52
	50	5.22	5.88	6.65	7.80	8.30	9.28
	100	5.31	5.01	6.87	8.58	8.28	7.87
	200	4.87	5.10	6.62	8.23	8.12	8.13
B	0	6.48	5.72	7.05	8.38	9.54	8.04
	50	5.95	5.63	6.42	7.78	8.03	8.54
	100	5.87	5.93	6.00	7.77	8.39	8.01
	200	5.89	5.75	5.92	7.59	7.99	7.40
LSD[a]		0.83	0.61	0.97	1.22	1.06	2.53
				1985B			
A	0	4.95	6.03	7.33	9.01	8.92	10.64
	50	4.59	4.65	6.29	7.33	8.87	10.79
	100	4.40	4.79	5.78	7.82	8.63	9.35
	200	4.27	4.93	5.25	6.96	8.55	9.69
B	0	4.84	5.55	7.65	9.35	9.45	10.35
	50	5.18	5.52	6.34	7.54	8.18	9.69
	100	5.02	5.97	6.38	7.03	8.17	9.25
	200	4.85	5.33	6.42	6.67	8.30	9.47
LSD[a]		0.46	0.75	0.76	0.75	1.52	1.25

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.7. Effect of various infestation periods and densities of potato leafhopper (PLH) on internodal stem distance (cm) at weekly sampling intervals for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	2.24	3.10	3.27	3.14	2.85	1.74
	50	2.45	2.76	3.32	2.80	2.66	2.80
	100	2.12	2.43	2.93	2.92	2.88	2.74
	200	1.94	2.35	2.59	2.35	2.43	2.74
B	0	2.12	2.86	3.69	3.47	3.92	3.69
	50	1.91	2.92	3.62	3.30	3.73	3.56
	100	1.91	2.95	3.45	3.22	3.43	3.38
	200	2.04	2.73	2.77	3.22	2.89	2.82
LSD[a]		0.45	0.38	0.53	0.61	0.36	0.57
				1985A			
A	0	2.32	4.96	4.93	4.29	4.57	4.01
	50	2.22	4.27	3.98	3.74	3.87	3.52
	100	2.06	4.48	4.03	3.62	3.94	3.73
	200	2.07	4.51	4.15	3.61	3.90	3.67
B	0	1.91	4.28	4.66	3.36	4.21	5.19
	50	1.81	3.93	3.73	3.34	3.49	3.49
	100	2.05	4.02	4.33	3.56	3.76	3.70
	200	2.03	4.26	4.26	3.91	3.85	3.66
LSD[a]		0.35	0.47	0.92	0.85	0.64	0.72
				1985B			
A	0	3.42	5.20	5.74	5.51	5.36	5.44
	50	3.09	5.58	5.67	5.25	5.33	5.18
	100	2.73	5.37	5.53	5.33	5.74	5.16
	200	2.63	5.06	5.38	5.19	5.38	5.69
B	0	2.83	4.93	5.47	5.79	5.69	5.43
	50	2.72	4.33	5.59	5.45	5.45	5.25
	100	2.78	4.69	5.20	5.46	5.60	5.13
	200	2.80	5.06	5.28	5.07	4.79	4.81
LSD[a]		0.26	0.92	0.73	0.79	1.11	0.71

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.8. Effect of various infestation periods and densities of potato leafhopper (PLH) on average adjusted leaf area per leaf (cm^2) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	0.62	0.60	0.52	0.46	0.43	0.22
	50	0.71	0.65	0.53	0.49	0.44	0.24
	100	0.73	0.57	0.54	0.54	0.37	0.25
	200	0.61	0.56	0.56	0.50	0.42	0.27
B	0	0.67	0.63	0.53	0.62	0.56	0.35
	50	0.59	0.59	0.67	0.63	0.57	0.36
	100	0.63	0.59	0.58	0.59	0.55	0.33
	200	0.57	0.60	0.56	0.58	0.47	0.33
LSD[a]		0.12	0.11	0.13	0.12	0.14	0.12
				1985A			
A	0	0.40	0.63	0.60	0.55	0.43	0.30
	50	0.34	0.55	0.58	0.47	0.40	0.34
	100	0.34	0.63	0.55	0.54	0.46	0.31
	200	0.27	0.61	0.55	0.48	0.35	0.32
B	0	0.34	0.61	0.61	0.52	0.39	0.29
	50	0.25	0.51	0.48	0.41	0.34	0.26
	100	0.32	0.53	0.56	0.49	0.37	0.24
	200	0.32	0.56	0.60	0.48	0.39	0.25
LSD[a]		0.09	0.13	0.09	0.14	0.09	0.07
				1985B			
A	0	0.52	0.91	0.79	0.78	0.74	0.69
	50	0.52	0.86	0.78	0.79	0.74	0.53
	100	0.51	0.86	0.80	0.80	0.68	0.49
	200	0.52	0.82	0.85	0.84	0.73	0.53
B	0	0.50	0.88	0.91	0.79	0.60	0.59
	50	0.48	0.79	0.91	0.95	0.73	0.52
	100	0.47	0.72	0.77	0.82	0.64	0.54
	200	0.49	0.83	0.72	0.76	0.74	0.52
LSD[a]		0.08	0.15	0.16	0.30	0.15	0.14

[a]LSD = least significant difference ($P = 0.05$).

Table C.9. Effect of various infestation periods and densities of potato leafhopper (PLH) on average leaf weight (mg) per leaf measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	3.08	3.21	2.99	3.19	3.12	1.76
	50	2.64	3.21	3.67	4.32	3.42	1.86
	100	2.81	2.99	3.68	4.58	3.33	2.03
	200	2.40	3.00	3.94	4.83	3.30	1.84
B	0	3.14	3.29	2.79	3.00	2.95	2.27
	50	2.61	3.11	2.93	2.86	2.97	2.52
	100	2.86	3.17	2.88	3.44	3.38	2.47
	200	2.57	2.90	2.73	3.07	3.62	2.16
LSD[a]		0.79	0.63	0.65	0.65	0.89	0.41
				1985A			
A	0	2.42	3.05	4.04	3.56	2.87	2.29
	50	2.34	2.90	3.76	3.38	2.84	2.11
	100	2.22	2.90	3.97	3.57	2.84	2.21
	200	2.31	2.75	4.52	3.36	2.43	2.16
B	0	2.35	3.15	4.13	3.19	2.59	2.11
	50	1.94	3.15	3.69	3.06	2.39	1.93
	100	2.32	3.11	3.99	3.46	2.56	1.99
	200	2.39	3.16	4.50	3.59	2.85	2.18
LSD[a]		0.42	0.41	0.83	0.62	0.45	0.36
				1985B			
A	0	2.95	3.59	4.63	2.94	2.74	2.68
	50	3.00	3.25	4.16	2.89	2.66	2.39
	100	2.90	3.42	4.20	2.90	2.50	2.39
	200	2.95	2.91	4.27	2.95	2.74	2.37
B	0	2.80	3.61	4.62	3.44	2.72	2.53
	50	2.67	3.07	4.67	3.00	2.89	2.12
	100	2.70	3.23	4.32	3.02	2.69	2.32
	200	2.71	3.34	4.66	3.47	2.86	2.97
LSD[a]		0.37	0.49	0.57	0.49	0.34	0.56

[a]LSD = least significant difference (*P* = 0.05).

Table C.10. Effect of various infestation periods and densities of potato leafhopper (PLH) on the adjusted leaf area ratio (cm^2/gm) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	124.6	88.6	83.5	66.2	63.2	43.1
	50	153.9	105.5	82.3	62.9	64.6	54.8
	100	154.3	92.6	76.3	65.7	55.7	50.0
	200	151.5	98.0	80.8	64.0	63.9	59.1
B	0	123.5	94.3	92.0	111.4	80.9	65.2
	50	131.6	93.1	126.2	107.8	83.2	59.2
	100	138.4	93.9	101.9	88.7	81.2	54.4
	200	128.7	105.3	111.7	102.1	72.3	66.7
LSD[a]		18.3	18.6	21.4	23.3	17.2	18.7
				1985A			
A	0	79.4	81.7	67.9	64.9	64.0	59.7
	50	74.2	78.5	74.1	66.5	69.0	74.4
	100	75.5	92.9	65.0	69.0	75.5	67.5
	200	65.3	93.1	62.5	70.0	70.1	73.7
B	0	75.6	83.5	65.5	71.0	64.7	56.0
	50	66.3	76.0	63.7	61.6	67.5	63.9
	100	71.8	76.5	68.3	65.4	64.1	55.4
	200	71.7	77.1	67.1	64.0	62.1	55.9
LSD[a]		20.8	14.1	9.5	9.5	8.3	17.4
				1985B			
A	0	78.1	110.1	68.5	94.3	107.6	87.5
	50	79.8	117.3	79.8	114.7	111.8	79.7
	100	82.7	110.3	81.6	110.3	100.3	76.1
	200	81.3	127.6	90.8	117.1	107.3	81.3
B	0	87.4	109.8	80.0	80.6	79.9	80.6
	50	85.3	115.7	89.2	119.1	92.8	97.9
	100	80.6	105.9	83.8	111.2	94.2	87.3
	200	84.9	108.7	73.2	96.3	109.2	65.3
LSD[a]		13.9	19.5	13.9	26.8	21.1	26.5

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.11. Effect of various infestation periods and densities of potato leafhopper (PLH) on the adjusted specific leaf area (cm^2/mg) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	0.22	0.19	0.18	0.15	0.14	0.12
	50	0.27	0.21	0.15	0.11	0.13	0.13
	100	0.26	0.19	0.15	0.12	0.11	0.12
	200	0.26	0.19	0.14	0.10	0.12	0.15
B	0	0.21	0.19	0.19	0.22	0.19	0.15
	50	0.23	0.19	0.23	0.22	0.19	0.14
	100	0.22	0.19	0.20	0.18	0.17	0.14
	200	0.22	0.21	0.21	0.19	0.14	0.15
LSD[a]		0.04	0.03	0.05	0.05	0.04	0.04
				1985A			
A	0	0.16	0.21	0.15	0.16	0.15	0.13
	50	0.15	0.19	0.15	0.14	0.14	0.16
	100	0.16	0.22	0.14	0.15	0.16	0.14
	200	0.12	0.22	0.13	0.14	0.14	0.15
B	0	0.15	0.19	0.15	0.16	0.15	0.14
	50	0.13	0.16	0.13	0.13	0.14	0.14
	100	0.14	0.17	0.14	0.14	0.14	0.12
	200	0.13	0.18	0.13	0.13	0.13	0.14
LSD[a]		0.04	0.03	0.02	0.03	0.02	0.04
				1985B			
A	0	0.18	0.25	0.17	0.27	0.28	0.24
	50	0.17	0.26	0.19	0.27	0.28	0.23
	100	0.18	0.25	0.19	0.28	0.27	0.21
	200	0.18	0.28	0.20	0.28	0.27	0.23
B	0	0.18	0.24	0.20	0.22	0.22	0.23
	50	0.18	0.26	0.20	0.31	0.26	0.25
	100	0.17	0.23	0.18	0.27	0.24	0.23
	200	0.18	0.25	0.16	0.22	0.26	0.18
LSD[a]		0.03	0.04	0.03	0.08	0.05	0.07

[a]LSD = least significant difference (P = 0.05).

Table C.12. Effect of various infestation periods and densities of potato leafhopper (PLH) on the leaf number ratio (no./gm) at weekly sampling intervals for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	209.4	152.7	165.1	146.5	155.1	241.8
	50	224.4	169.0	156.1	129.5	149.8	228.7
	100	213.8	167.8	142.9	123.8	152.6	205.7
	200	249.9	178.5	146.7	127.9	155.6	221.4
B	0	189.9	151.3	172.3	179.5	145.0	195.4
	50	227.5	162.3	190.2	174.9	149.3	166.1
	100	219.6	173.4	179.3	149.6	149.2	162.1
	200	234.4	179.9	199.0	174.6	154.4	205.8
LSD[a]		33.0	36.9	31.8	39.5	28.4	49.3
				1985A			
A	0	199.6	130.9	113.7	117.2	148.7	201.0
	50	219.6	145.1	128.8	142.1	170.6	219.8
	100	227.3	148.5	117.3	134.3	177.4	223.0
	200	239.3	153.9	114.5	149.5	199.6	232.3
B	0	223.1	139.4	108.1	136.6	166.9	195.0
	50	270.2	150.8	138.4	152.8	198.7	244.6
	100	229.2	146.5	124.1	138.3	178.7	231.0
	200	226.3	136.3	112.0	135.2	160.2	222.1
LSD[a]		39.8	21.5	26.5	30.7	33.4	38.0
				1985B			
A	0	149.5	123.3	87.3	119.9	145.0	135.6
	50	153.5	139.4	103.0	144.9	152.2	152.2
	100	164.4	128.0	101.7	136.8	148.9	156.9
	200	158.7	155.2	107.3	141.9	149.3	156.5
B	0	173.7	125.3	90.0	108.4	134.2	138.1
	50	178.7	147.6	97.9	127.6	127.7	187.2
	100	173.6	146.0	110.0	138.2	147.9	165.3
	200	172.5	132.1	101.4	127.3	146.7	129.8
LSD[a]		28.8	25.2	16.5	20.7	28.7	38.7

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.13. Effect of various infestation periods and densities of potato leafhopper (PLH) on the leaf weight ratio (gm/gm) at weekly sampling intervals for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	0.58	0.47	0.48	0.46	0.46	0.42
	50	0.58	0.51	0.55	0.56	0.50	0.42
	100	0.59	0.49	0.52	0.57	0.50	0.41
	200	0.59	0.52	0.56	0.62	0.51	0.41
B	0	0.58	0.48	0.48	0.53	0.42	0.44
	50	0.59	0.48	0.55	0.50	0.44	0.42
	100	0.63	0.49	0.50	0.51	0.50	0.40
	200	0.58	0.51	0.53	0.53	0.55	0.44
LSD[a]		0.08	0.04	0.06	0.10	0.07	0.07
				1985A			
A	0	0.48	0.40	0.46	0.42	0.42	0.46
	50	0.51	0.42	0.48	0.48	0.48	0.46
	100	0.49	0.43	0.46	0.47	0.47	0.48
	200	0.55	0.42	0.51	0.49	0.48	0.50
B	0	0.52	0.44	0.44	0.44	0.43	0.41
	50	0.52	0.47	0.49	0.47	0.47	0.47
	100	0.53	0.45	0.49	0.47	0.45	0.45
	200	0.53	0.43	0.50	0.48	0.45	0.48
LSD[a]		0.05	0.03	0.05	0.04	0.03	0.04
				1985B			
A	0	0.44	0.44	0.40	0.35	0.39	0.36
	50	0.46	0.46	0.43	0.42	0.41	0.35
	100	0.46	0.44	0.43	0.39	0.37	0.37
	200	0.46	0.45	0.46	0.41	0.40	0.36
B	0	0.49	0.45	0.41	0.37	0.36	0.35
	50	0.47	0.45	0.45	0.38	0.37	0.39
	100	0.47	0.46	0.47	0.42	0.39	0.38
	200	0.47	0.44	0.47	0.44	0.42	0.37
LSD[a]		0.04	0.06	0.04	0.04	0.05	0.05

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.14. Effect of various infestation periods and densities of potato leafhopper (PLH) on the specific leaf weight (mg/cm^2) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	4.77	5.37	5.79	6.94	7.27	8.07
	50	3.78	4.87	6.72	8.38	7.28	7.45
	100	3.78	5.31	6.58	8.07	7.70	7.90
	200	3.79	5.34	6.58	8.82	7.17	6.95
B	0	4.71	5.21	5.24	4.84	5.25	6.91
	50	4.46	5.22	4.49	4.65	5.14	7.06
	100	4.55	5.34	5.07	5.80	6.12	7.30
	200	4.53	4.81	5.04	5.24	7.47	6.59
LSD[a]		0.93	0.93	1.13	1.53	1.85	1.83
				1985A			
A	0	6.42	4.91	6.73	6.54	6.69	7.73
	50	6.92	5.36	6.45	6.96	6.94	6.74
	100	6.57	4.69	7.01	6.56	6.22	6.97
	200	9.34	4.65	7.95	6.59	6.61	6.59
B	0	7.13	5.33	6.75	6.11	6.68	7.31
	50	8.17	6.24	7.61	7.48	6.98	7.19
	100	7.43	6.06	7.18	6.92	6.80	7.72
	200	7.51	5.69	7.37	7.34	6.86	7.74
LSD[a]		1.60	0.77	1.14	1.12	0.90	1.54
				1985B			
A	0	5.68	3.97	5.84	3.80	3.75	4.32
	50	5.75	3.95	5.33	3.66	3.68	4.44
	100	5.54	3.98	5.31	3.63	3.75	4.90
	200	5.56	3.54	5.04	3.52	3.71	4.49
B	0	5.59	4.12	5.10	5.93	4.47	4.29
	50	5.69	3.95	5.12	3.22	3.93	4.11
	100	5.80	4.54	5.67	3.76	4.18	4.36
	200	5.52	4.05	6.43	4.45	3.99	5.58
LSD[a]		0.82	0.67	0.85	2.30	0.69	1.10

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.15. Effect of various infestation periods and densities of potato leafhopper (PLH) on the net assimilation rate ($mg/cm^2/m^2$ of land) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	---	1.18	0.57	0.25	0.16	0.47
	50	---	0.92	0.50	1.10	0.73	0.27
	100	---	1.00	0.64	0.68	0.47	0.20
	200	---	0.96	0.66	0.83	0.84	0.07
B	0	---	1.58	0.56	0.14	0.00	0.15
	50	---	1.95	0.78	0.36	0.35	0.73
	100	---	1.54	0.43	0.68	0.62	0.85
	200	---	1.24	0.21	0.06	0.57	0.33
LSD[a]		---	0.82	0.56	0.68	0.71	0.85
				1985A			
A	0	---	0.81	0.29	0.27	0.10	1.03
	50	---	0.38	0.06	0.00	0.11	0.46
	100	---	0.20	0.00	0.00	0.04	0.19
	200	---	0.24	0.34	0.03	0.00	0.61
B	0	---	0.21	0.30	0.56	0.25	0.93
	50	---	0.06	0.13	0.11	0.09	0.00
	100	---	0.38	0.15	0.10	0.51	0.04
	200	---	0.60	0.42	0.03	0.20	0.17
LSD[a]		---	0.69	0.37	0.40	0.56	0.71
				1985B			
A	0	---	0.33	1.10	0.73	0.16	0.01
	50	---	0.37	0.60	0.41	0.58	0.53
	100	---	0.58	0.68	0.25	0.70	0.77
	200	---	0.28	0.24	0.23	0.92	0.57
B	0	---	0.36	0.65	0.86	0.27	0.00
	50	---	0.64	0.84	0.34	0.68	0.32
	100	---	0.39	0.45	0.00	0.10	0.34
	200	---	0.41	0.73	0.13	0.52	0.70
LSD[a]		---	0.53	0.65	0.62	0.71	0.87

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.16. Effect of various infestation periods and densities of potato leafhopper (PLH) on crop growth rate (gm/m^2 of land/day) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	---	11.03	12.53	8.99	5.63	13.06
	50	---	8.11	8.87	25.09	17.86	7.83
	100	---	7.60	13.22	18.13	11.88	5.28
	200	---	6.95	12.00	16.13	18.46	1.34
B	0	---	18.04	11.56	4.03	0.00	4.04
	50	---	20.65	12.13	10.19	10.66	17.19
	100	---	19.38	8.48	19.17	16.57	23.24
	200	---	14.06	3.68	1.22	13.69	9.47
LSD[a]		---	7.83	9.22	16.77	16.94	21.98
				1985A			
A	0	---	11.38	7.07	6.64	2.29	30.09
	50	---	4.96	1.06	0.00	2.11	9.72
	100	---	2.35	0.00	0.00	0.82	3.52
	200	---	2.75	4.98	0.60	0.00	11.41
B	0	---	3.21	7.39	14.19	7.48	25.44
	50	---	0.83	2.70	2.39	1.49	0.00
	100	---	5.41	3.28	3.35	13.11	0.99
	200	---	8.87	6.86	0.60	4.69	4.04
LSD[a]		---	9.23	7.90	9.11	14.16	18.35
				1985B			
A	0	---	8.27	25.55	20.88	5.60	0.40
	50	---	4.86	10.52	8.57	17.07	16.99
	100	---	8.86	13.69	6.65	21.07	13.97
	200	---	3.83	5.12	6.59	30.16	16.14
B	0	---	7.53	19.05	23.51	8.04	0.00
	50	---	10.31	15.34	7.39	14.90	7.68
	100	---	7.69	8.93	0.00	2.40	6.79
	200	---	8.19	14.91	2.98	14.31	12.78
LSD[a]		---	8.57	12.74	16.72	21.20	19.32

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.17. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem growth rate (gm/m^2 of land/day) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	---	6.03	5.97	2.00	0.72	7.75
	50	---	3.70	2.26	7.59	7.12	4.55
	100	---	3.58	4.29	2.87	4.45	3.98
	200	---	2.80	3.53	4.95	8.01	1.16
B	0	---	9.42	5.10	0.61	0.00	1.63
	50	---	10.56	4.85	5.27	3.71	8.18
	100	---	9.73	3.75	8.97	6.43	16.83
	200	---	6.45	0.49	0.76	3.51	5.39
LSD[a]		---	4.55	3.83	7.45	7.35	15.95
				1985A			
A	0	---	8.28	4.63	4.42	1.17	14.97
	50	---	3.81	1.79	0.00	1.67	5.18
	100	---	1.98	0.00	1.33	1.21	1.22
	200	---	2.81	3.17	2.80	0.00	4.06
B	0	---	2.55	5.37	10.92	3.37	16.61
	50	---	0.50	2.72	2.78	0.00	0.00
	100	---	3.35	2.78	4.08	8.65	0.79
	200	---	6.16	4.16	2.02	4.11	2.22
LSD[a]		---	5.97	5.55	8.03	8.95	12.85
				1985B			
A	0	---	4.56	17.39	14.95	4.26	3.33
	50	---	2.30	7.88	5.83	12.89	13.69
	100	---	4.79	8.87	6.05	17.23	11.66
	200	---	1.93	3.45	5.38	21.68	14.97
B	0	---	4.44	12.91	23.36	8.91	0.16
	50	---	5.99	8.86	5.68	11.15	7.30
	100	---	4.41	4.90	0.53	3.92	5.72
	200	---	4.45	9.21	2.00	8.35	12.97
LSD[a]		---	4.87	7.19	11.60	13.91	14.19

[a]LSD = least significant difference (P = 0.05).

Table C.18. Effect of various infestation periods and densities of potato leafhopper (PLH) on leaf growth rate (gm/m^2 of land/day) measured weekly for each of three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	---	5.07	6.56	6.99	8.42	5.31
	50	---	4.65	7.02	18.99	11.60	3.28
	100	---	4.02	8.93	16.01	8.14	1.47
	200	---	4.15	8.76	14.04	10.83	0.19
B	0	---	8.62	6.46	3.70	0.53	3.47
	50	---	10.09	8.57	5.26	6.95	9.01
	100	---	9.65	5.12	11.07	10.14	7.17
	200	---	7.62	3.49	0.85	11.65	4.09
LSD[a]		---	3.50	5.84	9.57	11.19	7.20
				1985A			
A	0	---	3.27	2.44	2.22	1.12	16.45
	50	---	1.53	0.00	0.00	0.45	5.10
	100	---	0.41	0.00	0.00	0.00	3.70
	200	---	0.69	2.46	0.00	0.00	7.56
B	0	---	0.67	2.02	3.27	4.12	8.84
	50	---	0.33	0.39	0.00	1.53	0.00
	100	---	2.06	0.50	0.00	5.08	1.95
	200	---	2.97	3.16	0.87	1.20	1.83
LSD[a]		---	3.46	3.06	2.80	5.45	5.50
				1985B			
A	0	---	3.70	8.16	6.42	1.47	0.00
	50	---	2.98	3.42	2.74	5.12	4.07
	100	---	4.06	5.17	1.10	3.92	2.61
	200	---	1.98	2.15	1.55	8.48	2.49
B	0	---	3.09	6.14	10.17	1.19	0.00
	50	---	4.31	6.53	1.84	4.54	0.50
	100	---	3.27	4.37	0.00	0.00	1.95
	200	---	3.74	5.70	0.98	5.96	1.71
LSD[a]		---	3.86	6.19	5.32	8.06	4.65

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.19. Effect of various infestation periods and densities of potato leafhopper (PLH) on the weekly adjusted leaf area growth rate (cm^2/m^2 of land/day) for each of three field trials

Infest Period	PLH Density	7	14	21	28	35	Har
				Days after cutting			
				1984			
A	0	---	0.10	0.06	0.05	0.00	0.00
	50	---	0.11	0.00	0.11	0.03	0.00
	100	---	0.08	0.03	0.05	0.01	0.00
	200	---	0.08	0.05	0.05	0.00	0.00
B	0	---	0.17	0.07	0.08	0.08	0.05
	50	---	0.19	0.15	0.09	0.02	0.03
	100	---	0.19	0.07	0.19	0.06	0.00
	200	---	0.17	0.04	0.08	0.02	0.00
LSD[a]		---	0.08	0.11	0.13	0.09	0.06
				1985A			
A	0	---	0.07	0.00	0.01	0.02	0.24
	50	---	0.02	0.01	0.00	0.03	0.12
	100	---	0.02	0.00	0.00	0.06	0.07
	200	---	0.01	0.01	0.01	0.02	0.10
B	0	---	0.01	0.00	0.03	0.00	0.11
	50	---	0.00	0.00	0.00	0.00	0.00
	100	---	0.00	0.00	0.00	0.07	0.02
	200	---	0.02	0.01	0.00	0.01	0.00
LSD[a]		---	0.07	0.01	0.03	0.09	0.10
				1985B			
A	0	---	0.11	0.18	0.28	0.24	0.16
	50	---	0.11	0.09	0.19	0.35	0.12
	100	---	0.13	0.16	0.21	0.32	0.12
	200	---	0.01	0.13	0.16	0.40	0.17
B	0	---	0.09	0.20	0.42	0.17	0.07
	50	---	0.12	0.20	0.26	0.20	0.19
	100	---	0.08	0.11	0.11	0.13	0.14
	200	---	0.11	0.12	0.10	0.29	0.12
LSD[a]		---	0.12	0.14	0.17	0.28	0.20

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table C.20. Effect of various infestation periods and densities of potato leafhopper (PLH) on the daily accumulation of damaged leaves (no./day) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
		1984					
A	0	---	0.25	1.36	2.87	0.66	6.25
	50	---	0.77	1.56	3.45	1.41	2.05
	100	---	0.97	1.71	3.54	1.82	2.31
	200	---	1.00	0.16	1.86	1.12	0.70
B	0	---	0.84	3.47	1.77	0.68	4.33
	50	---	1.57	2.49	3.42	1.60	2.88
	100	---	1.26	1.20	3.82	0.75	2.95
	200	---	0.80	0.68	2.48	2.21	1.54
LSD[a]		---	1.04	1.93	3.05	2.32	5.53
		1985A					
A	0	---	2.81	1.03	2.08	5.05	8.99
	50	---	1.77	0.62	0.36	3.63	6.68
	100	---	1.07	0.33	0.81	3.40	2.92
	200	---	1.09	1.33	2.96	5.07	6.95
B	0	---	1.79	0.29	1.51	7.72	9.80
	50	---	0.83	0.75	0.11	5.15	6.18
	100	---	1.59	0.13	0.67	5.54	6.01
	200	---	1.90	0.59	0.11	3.43	3.42
LSD[a]		---	1.30	1.37	2.34	5.71	5.61
		1985B					
A	0	---	0.59	1.08	3.85	0.07	0.00
	50	---	0.11	0.82	1.52	2.96	1.30
	100	---	0.33	0.07	1.37	1.38	3.11
	200	---	1.01	0.00	0.31	0.41	1.82
B	0	---	0.78	0.66	2.85	0.44	0.13
	50	---	0.79	0.33	0.82	0.00	0.95
	100	---	1.47	0.77	1.44	0.00	1.49
	200	---	1.06	1.06	0.35	2.48	2.69
LSD[a]		---	1.26	1.17	2.16	2.88	3.69

[a]LSD = least significant difference (*P* = 0.05).

APPENDIX D. MEANS AND ANALYSIS FOR QUALITY AND COMPONENT QUALITY VARIABLES

Table D.1. Effect of various infestation periods and densities of potato leafhopper (PLH) on the leaf:stem ratio (gm/gm) measured weekly for each of three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	1.48	0.89	0.93	0.86	0.87	0.73
	50	1.40	1.05	1.26	1.28	1.01	0.72
	100	1.46	0.97	1.08	1.33	1.01	0.69
	200	1.44	1.09	1.31	1.67	1.06	0.69
B	0	1.40	0.94	0.92	1.15	0.74	0.79
	50	1.44	0.94	1.29	1.08	0.78	0.72
	100	1.76	0.96	1.02	1.05	1.05	0.68
	200	1.43	1.03	1.15	1.17	1.25	0.78
LSD[a]		0.55	0.17	0.31	0.53	0.31	0.19
				1985A			
A	0	0.93	0.66	0.84	0.71	0.74	0.85
	50	1.05	0.72	0.94	0.93	0.93	0.86
	100	0.98	0.75	0.86	0.90	0.90	0.92
	200	1.23	0.73	1.05	0.96	0.94	1.00
B	0	1.10	0.78	0.80	0.77	0.76	0.70
	50	1.09	0.88	0.98	0.88	0.89	0.89
	100	1.11	0.83	0.98	0.88	0.82	0.84
	200	1.14	0.76	1.02	0.94	0.83	0.94
LSD[a]		0.21	0.09	0.22	0.16	0.10	0.14
				1985B			
A	0	0.80	0.79	0.67	0.55	0.65	0.56
	50	0.84	0.88	0.75	0.72	0.69	0.54
	100	0.85	0.78	0.74	0.66	0.59	0.60
	200	0.56	0.84	0.84	0.71	0.66	0.57
B	0	0.95	0.82	0.69	0.58	0.56	0.53
	50	0.90	0.82	0.83	0.62	0.60	0.63
	100	0.88	0.87	0.89	0.73	0.66	0.61
	200	0.88	0.79	0.88	0.79	0.72	0.58
LSD[a]		0.13	0.19	0.12	0.11	0.12	0.11

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.2. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage <u>in-vitro</u> digestibility (%) measured weekly for each of three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	75.80	67.28	70.88	71.65	69.40	66.35
	50	75.43	70.98	73.00	73.28	70.60	64.00
	100	74.33	68.98	70.38	70.85	71.95	64.68
	200	74.88	68.50	72.48	73.63	64.93	63.45
B	0	75.10	67.08	72.53	71.55	69.60	67.20
	50	75.78	70.93	73.13	71.60	70.35	68.30
	100	74.68	72.08	72.60	71.43	69.38	64.85
	200	73.58	67.95	73.55	71.05	72.98	68.05
LSD[a]		4.37	3.38	2.18	3.33	3.95	2.73
				1985A			
A	0	80.55	77.85	74.03	74.13	63.70	67.13
	50	81.33	78.35	74.85	74.93	70.15	69.93
	100	78.33	78.38	74.93	71.68	68.80	68.13
	200	79.63	78.93	71.70	72.43	70.00	66.80
B	0	81.40	77.10	74.05	72.45	69.03	64.93
	50	78.90	78.03	74.93	72.33	68.78	68.53
	100	79.36	80.40	76.40	72.35	69.65	68.18
	200	79.96	78.28	76.55	74.30	68.50	68.98
LSD[a]		3.57	3.01	3.89	3.79	4.66	4.49
				1985B			
A	0	78.13	76.20	76.58	73.28	63.15	64.95
	50	72.83	76.45	74.83	74.40	62.88	65.25
	100	77.88	74.80	75.18	72.10	63.33	66.48
	200	77.28	74.63	75.30	68.93	64.10	66.15
B	0	76.10	76.70	75.20	73.85	64.98	65.88
	50	77.10	75.90	78.35	69.78	64.60	66.38
	100	75.98	76.13	76.58	72.83	63.48	64.78
	200	74.53	74.63	74.98	72.80	62.73	63.78
LSD[a]		6.27	4.32	3.20	3.16	4.51	3.72

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.3. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf *in-vitro* digestibility (%) measured for each of three field trials

Infest Period	PLH Density	Stem IVDDM 14	Stem IVDDM 28	Stem IVDDM Har	Leaf IVDDM 14	Leaf IVDDM 28	Leaf IVDDM Har
				1984			
A	0	---	65.50	60.50	---	80.00	80.20
	50	---	70.10	61.25	---	79.90	80.85
	100	---	72.40	59.60	---	80.30	75.85
	200	---	67.70	61.90	---	80.60	81.25
B	0	---	69.40	63.10	---	80.50	77.80
	50	---	70.35	60.25	---	80.40	79.40
	100	---	70.20	60.20	---	80.30	78.90
	200	---	69.85	62.05	---	81.80	78.85
LSD[a]		---	4.47	2.92	---	1.41	3.23
				1985A			
A	0	74.43	62.13	56.15	79.68	79.25	75.25
	50	75.65	61.55	56.88	78.70	78.53	77.15
	100	76.18	60.25	55.28	79.05	79.63	76.80
	200	75.85	62.93	57.63	78.03	79.28	75.20
B	0	74.65	62.98	57.40	81.10	75.16	76.05
	50	72.73	61.68	55.80	79.20	77.18	76.30
	100	74.53	60.38	57.78	79.15	78.48	74.45
	200	73.68	61.08	60.00	81.88	78.83	77.80
LSD[a]		4.24	4.01	4.16	2.78	3.26	2.51
				1985B			
A	0	72.95	59.88	52.38	83.95	72.50	67.63
	50	73.93	62.43	52.60	82.85	74.48	65.70
	100	74.70	64.83	51.43	80.98	75.03	65.00
	200	75.90	62.20	53.60	81.93	76.10	66.00
B	0	74.98	62.33	51.18	82.43	72.40	63.73
	50	77.10	62.08	51.35	81.93	75.05	64.15
	100	72.88	65.83	52.20	82.00	78.43	63.38
	200	75.78	63.95	54.60	82.00	78.83	68.38
LSD[a]		2.93	3.83	3.91	1.96	3.96	5.89

[a]LSD = least significant difference (*P* = 0.05).

Table D.4. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage crude protein (%) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	30.85	21.50	22.80	21.50	19.65	18.98
	50	31.10	22.05	20.25	18.98	19.55	19.76
	100	29.23	24.23	21.88	18.93	17.73	18.65
	200	28.90	22.23	20.55	17.50	17.18	17.28
B	0	30.58	23.18	27.73	23.58	21.70	21.03
	50	31.78	24.43	25.43	24.20	21.15	21.15
	100	30.88	24.65	24.33	21.93	20.68	19.98
	200	28.05	23.05	23.35	22.43	20.68	20.08
LSD[a]		2.93	4.52	2.33	2.66	1.48	2.29
				1985A			
A	0	39.58	32.93	23.60	26.38	20.63	21.25
	50	42.60	32.38	22.98	24.83	21.70	22.18
	100	38.90	31.58	26.43	26.43	20.48	22.10
	200	40.60	31.83	23.58	21.95	21.15	21.40
B	0	38.10	33.78	24.43	24.95	20.08	20.15
	50	38.13	30.05	24.50	26.00	23.15	20.40
	100	38.86	31.30	23.43	24.08	21.48	20.95
	200	38.08	31.33	22.28	23.08	20.50	20.75
LSD[a]		3.53	2.14	2.89	3.17	4.13	3.39
				1985B			
A	0	39.75	34.63	25.25	26.15	24.33	22.73
	50	38.78	35.50	25.30	24.68	22.88	23.45
	100	36.70	34.13	25.43	24.35	23.43	23.30
	200	37.90	36.23	27.93	25.13	25.15	21.43
B	0	37.80	34.78	27.20	25.60	26.28	24.48
	50	37.13	34.33	27.45	25.45	25.58	23.75
	100	37.48	37.35	25.75	25.58	25.20	22.75
	200	36.45	33.28	27.43	24.83	22.88	22.95
LSD[a]		2.47	3.39	4.85	4.32	3.57	3.08

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.5. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf crude protein (%) measured for each of three field trials

		Stem Protein			Leaf Protein		
Infest Period	PLH Density	14	28	Har	14	28	Har
				1984			
A	0	---	15.85	14.00	---	32.50	25.85
	50	---	15.85	13.60	---	31.80	22.25
	100	---	17.20	13.75	---	31.50	21.50
	200	---	18.00	14.25	---	27.20	17.80
B	0	---	16.70	14.25	---	36.80	29.40
	50	---	17.45	14.50	---	34.90	29.00
	100	---	18.15	14.50	---	36.10	25.80
	200	---	17.90	15.50	---	35.30	24.35
LSD[a]		---	1.25	0.71	---	0.86	1.87
				1985A			
A	0	23.38	15.00	13.05	42.65	30.03	31.50
	50	26.13	15.05	14.60	41.20	30.03	31.50
	100	26.48	14.78	14.23	44.60	29.25	29.35
	200	25.48	15.43	14.53	40.80	27.18	31.88
B	0	24.70	15.35	13.78	40.80	28.20	29.65
	50	24.95	15.90	14.53	39.35	26.85	30.20
	100	26.28	15.83	13.80	40.15	26.75	28.63
	200	25.00	15.30	14.28	41.15	23.53	26.93
LSD[a]		2.60	1.89	1.28	5.13	2.13	2.09
				1985B			
A	0	24.43	15.33	15.85	42.18	32.88	31.63
	50	25.23	15.28	17.68	44.18	34.98	30.43
	100	25.78	16.13	14.93	42.00	33.63	31.75
	200	25.83	17.00	15.05	43.98	33.23	32.70
B	0	25.03	16.63	15.15	42.55	30.88	33.45
	50	27.48	16.15	15.58	42.30	32.25	32.40
	100	23.25	15.70	15.20	42.55	32.18	33.58
	200	25.98	17.88	16.45	43.55	31.88	32.53
LSD[a]		2.85	2.07	3.36	3.37	3.81	2.43

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.6. Effect of various infestation periods and densities of potato leafhopper (PLH) on neutral-detergent fiber (NDF=cell soluble concentration) for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	46.53	44.08	49.68	49.25	46.50	45.03
	50	39.95	48.03	46.08	42.85	44.73	44.53
	100	45.55	44.25	49.00	41.80	42.20	39.00
	200	47.63	41.75	45.73	42.25	49.03	38.58
B	0	46.78	46.45	55.60	45.50	48.08	50.80
	50	50.15	51.68	54.18	49.68	45.05	43.20
	100	43.25	47.85	50.23	47.35	47.80	43.73
	200	45.58	46.90	47.73	41.33	46.58	41.43
LSD[a]		7.59	10.24	9.05	8.27	7.17	6.98
				1985A			
A	0	64.50	51.63	47.58	43.60	39.40	47.58
	50	61.28	52.08	42.03	46.08	45.75	42.03
	100	65.13	49.80	46.28	41.80	32.93	46.28
	200	59.70	54.65	43.93	36.85	43.05	43.93
B	0	63.83	56.18	44.23	51.85	41.23	44.23
	50	59.00	47.30	41.73	42.50	47.50	41.73
	100	68.86	51.83	41.03	41.65	38.28	41.03
	200	62.04	49.55	43.68	41.65	42.60	43.68
LSD[a]		7.47	6.56	8.53	9.33	10.80	8.53
				1985B			
A	0	55.68	44.38	40.33	43.13	35.68	28.88
	50	55.58	49.50	42.68	45.43	37.98	36.80
	100	53.03	45.45	45.55	41.40	36.00	37.65
	200	56.33	45.30	45.90	41.28	37.70	43.38
B	0	56.15	46.88	43.58	44.23	37.73	32.10
	50	50.45	46.73	48.63	44.78	40.33	38.25
	100	53.13	45.78	45.28	44.78	37.25	35.60
	200	50.80	49.75	50.00	46.68	35.48	38.30
LSD[a]		7.69	5.21	9.88	5.11	5.67	8.02

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.7. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf neutral-detergent fiber (NDF=cell soluble concentration) for three field trials

Infest Period	PLH Density	Stem NDF 14	Stem NDF 28	Stem NDF Har	Leaf NDF 14	Leaf NDF 28	Leaf NDF Har
				1984			
A	0	---	43.65	36.80	---	62.20	54.35
	50	---	44.25	34.80	---	59.20	54.05
	100	---	43.00	34.80	---	55.50	52.35
	200	---	44.90	35.25	---	42.90	54.30
B	0	---	43.10	40.90	---	60.40	57.95
	50	---	47.10	34.85	---	61.00	62.05
	100	---	38.50	36.80	---	63.00	60.50
	200	---	47.80	34.90	---	63.0	60.50
LSD[a]		---	3.89	3.42	---	7.30	4.80
				1985A			
A	0	50.90	37.43	38.93	65.35	59.88	66.35
	50	47.75	42.33	40.35	61.30	60.38	65.43
	100	49.13	42.38	32.43	64.88	59.05	61.00
	200	49.23	44.38	35.80	62.28	56.93	65.75
B	0	43.35	36.45	32.23	63.83	56.43	62.50
	50	43.10	41.90	36.25	64.45	56.30	62.55
	100	48.38	44.23	38.50	59.05	56.08	58.13
	200	47.20	42.88	38.68	57.90	54.53	56.73
LSD[a]		5.89	5.86	5.99	5.14	4.81	8.42
				1985B			
A	0	46.03	33.68	33.33	61.88	48.63	48.75
	50	49.55	34.28	30.90	62.00	44.95	47.88
	100	40.43	33.28	34.53	55.80	44.23	48.48
	200	49.50	37.38	29.45	63.55	49.38	49.08
B	0	43.10	37.68	32.18	55.23	56.38	48.53
	50	45.03	39.88	33.10	64.45	49.55	50.33
	100	38.33	38.95	30.03	61.43	49.10	45.00
	200	37.03	38.80	31.38	65.48	43.15	50.53
LSD[a]		12.63	4.90	7.52	10.92	11.16	8.92

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.8. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage dry matter intake (DMI, gm/w $kg^{0.75}$) for three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	187.56	185.71	189.83	189.52	187.46	186.43
	50	182.35	188.52	187.23	184.66	186.23	186.08
	100	186.73	185.54	189.32	184.05	184.35	181.79
	200	188.37	183.96	186.97	184.33	189.37	181.52
B	0	187.51	187.19	193.95	186.74	188.66	190.62
	50	190.11	191.20	192.98	189.78	186.39	185.02
	100	185.13	188.45	190.12	188.11	188.45	185.48
	200	186.84	187.81	188.03	183.68	187.60	183.71
LSD[a]		5.73	7.55	6.57	6.17	5.22	5.24
				1985A			
A	0	199.68	191.22	188.32	185.28	182.05	188.32
	50	197.56	191.53	184.14	187.16	186.99	184.14
	100	200.07	189.79	187.26	184.04	176.96	187.26
	200	196.64	193.32	185.60	179.99	184.91	185.60
B	0	199.29	194.36	185.87	191.39	183.35	185.87
	50	196.15	187.85	183.93	184.34	188.27	183.93
	100	202.42	191.31	183.35	183.87	181.15	183.35
	200	198.20	189.85	185.39	183.92	184.59	185.39
LSD[a]		4.72	4.71	6.45	7.14	8.44	6.45
				1985B			
A	0	193.93	185.98	182.81	184.99	179.22	173.57
	50	193.94	189.71	184.50	186.71	181.08	180.14
	100	192.21	186.78	186.82	183.74	179.51	180.83
	200	194.43	186.64	187.02	183.63	180.69	185.16
B	0	194.34	187.82	185.25	185.76	180.89	176.20
	50	190.32	187.68	188.98	186.28	182.90	181.28
	100	192.22	186.96	186.64	186.28	180.51	179.14
	200	190.32	189.90	190.06	187.64	179.08	181.30
LSD[a]		5.44	3.81	7.40	3.80	4.39	6.51

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.9. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf dry matter intake (DMI, gm/w $kg^{0.75}$) for three field trials

Infest Period	PLH Density	Stem DMI 14	Stem DMI 28	Stem DMI Har	Leaf Protein 14	Leaf Protein 28	Leaf Protein Har
				1984			
A	0	---	133.61	143.32	---	92.80	112.50
	50	---	132.68	145.63	---	100.90	113.30
	100	---	134.31	145.42	---	110.00	117.20
	200	---	130.92	144.64	---	130.90	112.90
B	0	---	134.53	137.69	---	98.10	104.20
	50	---	127.54	145.56	---	96.40	93.50
	100	---	141.14	143.36	---	91.00	97.70
	200	---	125.92	145.55	---	109.30	95.60
LSD[a]		---	6.69	4.19	---	13.30	11.86
				1985A			
A	0	120.15	141.30	140.58	83.54	99.30	80.28
	50	126.25	135.28	138.64	95.34	97.90	83.34
	100	123.20	135.64	147.92	85.32	100.77	95.66
	200	123.22	132.42	144.41	92.73	106.67	81.98
B	0	133.33	143.61	147.46	88.33	107.81	91.80
	50	134.37	135.94	143.03	86.81	108.27	90.89
	100	125.11	132.55	140.70	101.42	108.15	103.83
	200	127.31	134.86	140.83	104.22	112.41	106.85
LSD[a]		10.83	7.79	6.46	14.12	11.78	23.47
				1985B			
A	0	128.59	146.78	147.16	92.27	123.38	124.22
	50	120.40	145.81	149.28	92.61	129.06	125.47
	100	137.85	147.15	145.79	109.14	132.35	124.30
	200	122.40	142.57	149.86	87.92	121.40	122.87
B	0	132.05	141.57	148.00	110.10	108.05	124.82
	50	129.51	139.32	145.99	85.82	122.86	119.78
	100	137.89	140.22	148.46	91.87	122.92	131.25
	200	141.97	140.36	148.88	83.57	132.44	119.58
LSD[a]		19.30	6.04	5.86	29.08	19.71	16.17

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.10. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage digestible dry matter intake (DDMI, gm/w kg$^{0.75}$) concentration) for three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	142.13	124.93	134.55	135.82	130.00	123.70
	50	137.46	134.12	136.68	135.33	131.49	119.06
	100	138.67	128.28	133.32	130.41	130.78	117.58
	200	141.02	126.21	135.50	135.75	122.91	115.18
B	0	140.83	125.92	140.67	133.70	131.33	128.14
	50	144.09	135.56	141.14	135.95	131.11	126.41
	100	138.26	135.86	138.06	134.30	130.74	120.26
	200	137.49	127.53	138.26	130.51	135.02	125.03
LSD[a]		8.06	8.56	6.81	8.87	7.42	7.53
				1985A			
A	0	160.83	148.85	139.39	137.38	116.03	126.42
	50	160.70	150.09	137.87	140.26	131.19	128.75
	100	156.78	148.75	140.40	131.92	121.80	127.60
	200	156.55	152.58	132.98	130.29	129.50	123.88
B	0	162.21	149.86	137.62	138.68	126.60	120.66
	50	154.76	146.48	137.87	133.35	129.43	126.05
	100	160.66	153.84	140.16	133.02	126.14	124.95
	200	158.51	148.52	141.87	136.66	126.39	127.87
LSD[a]		8.54	6.63	9.34	9.31	10.70	8.79
				1985B			
A	0	151.49	141.76	140.02	135.57	113.30	112.81
	50	141.25	144.99	137.99	138.98	113.86	117.58
	100	149.69	139.71	140.43	132.48	113.76	120.24
	200	150.27	139.30	140.76	126.55	116.18	122.45
B	0	147.92	144.08	139.33	137.25	117.53	116.08
	50	146.70	142.46	148.11	129.99	118.20	120.34
	100	146.08	142.35	142.91	135.65	114.57	116.03
	200	141.90	141.72	142.52	136.49	112.39	115.53
LSD[a]		13.25	8.83	7.90	6.28	10.27	8.29

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.11. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf digestible dry matter intake (DDMI, gm/w $kg^{0.75}$) for three field trials

Infest Period	PLH Density	Stem DDMI 14	Stem DDMI 28	Stem DDMI Har	Leaf DDMI 14	Leaf DDMI 28	Leaf DDMI Har
				1984			
A	0	---	87.57	86.71	---	74.10	90.27
	50	---	93.01	89.20	---	80.60	91.53
	100	---	97.57	86.75	---	88.30	88.67
	200	---	88.43	89.58	---	105.70	91.74
B	0	---	93.37	86.88	---	79.00	81.13
	50	---	89.77	87.66	---	77.50	74.28
	100	---	99.07	86.31	---	73.00	77.07
	200	---	87.87	90.32	---	89.40	75.32
LSD[a]		---	8.51	5.61	---	11.80	8.43
				1985A			
A	0	89.33	87.70	79.01	66.56	78.64	60.28
	50	95.50	83.28	78.88	74.97	76.76	64.26
	100	93.80	81.72	81.79	67.51	80.18	73.46
	200	93.38	83.33	83.18	72.42	84.54	61.50
B	0	99.61	90.45	84.65	71.81	80.90	69.85
	50	97.87	83.87	79.77	68.75	83.55	69.34
	100	93.27	79.92	81.23	80.29	85.06	77.29
	200	93.93	82.40	84.48	85.29	88.61	83.12
LSD[a]		10.32	7.02	7.13	11.61	9.84	17.70
				1985B			
A	0	93.59	87.92	77.09	77.44	89.46	84.02
	50	88.74	91.04	78.56	76.57	96.32	82.31
	100	103.08	95.34	74.95	88.43	99.30	80.91
	200	93.05	88.69	80.39	72.12	92.39	81.21
B	0	99.08	88.25	75.65	90.62	78.27	79.55
	50	99.73	86.48	74.87	70.34	92.21	77.04
	100	101.99	92.18	77.57	75.12	96.36	83.27
	200	107.50	89.78	81.23	68.71	98.72	81.77
LSD[a]		14.43	6.30	5.93	24.09	15.62	14.44

[a]LSD = least significant difference (*P* = 0.05).

Table D.12. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage relative feed value for three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	203.04	178.48	192.22	194.03	185.72	176.72
	50	196.38	191.60	195.26	193.34	187.85	170.09
	100	198.11	183.26	190.46	186.30	186.83	167.97
	200	201.46	180.30	193.58	193.93	175.59	164.55
B	0	201.18	179.89	200.96	191.00	187.62	183.07
	50	205.85	193.66	201.64	194.22	187.31	180.59
	100	197.51	194.08	197.24	191.86	186.78	171.80
	200	196.42	182.18	197.51	186.45	192.89	178.62
LSD[a]		11.51	12.23	9.73	12.67	10.60	10.75
				1985A			
A	0	229.77	212.65	199.13	196.26	165.76	180.61
	50	229.58	214.42	196.96	200.38	187.42	183.93
	100	223.97	212.50	200.58	188.46	174.01	182.29
	200	223.65	217.98	189.97	186.14	185.00	176.97
B	0	231.73	214.08	196.60	198.11	180.86	172.38
	50	221.09	209.26	196.96	190.51	184.91	180.07
	100	229.53	219.77	200.34	190.04	180.20	178.50
	200	226.45	212.17	202.67	195.24	180.56	182.67
LSD[a]		12.20	9.48	13.36	13.29	15.29	12.55
				1985B			
A	0	216.41	202.52	200.03	193.67	161.86	161.16
	50	201.78	207.14	197.13	198.55	162.66	167.97
	100	213.85	199.59	200.62	189.26	162.47	171.77
	200	214.68	199.00	201.08	180.79	165.97	174.94
B	0	211.31	205.83	199.05	196.08	167.90	165.84
	50	209.57	203.52	211.59	185.70	168.85	171.91
	100	208.69	203.35	204.16	193.79	163.68	165.76
	200	202.46	202.60	203.60	194.99	160.56	165.05
LSD[a]		18.93	12.61	11.28	8.97	14.67	11.84

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.13. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf relative feed value (RFV) for three field trials

Infest Period	PLH Density	Stem RFV 14	Stem RFV 28	Stem RFV Har	Leaf RFV 14	Leaf RFV 28	Leaf RFV Har
				1984			
A	0	---	125.10	123.88	---	105.90	129.00
	50	---	132.87	127.43	---	115.20	130.80
	100	---	139.39	123.94	---	126.10	126.70
	200	---	126.34	127.97	---	151.00	131.10
B	0	---	133.39	124.12	---	112.90	115.90
	50	---	128.24	125.24	---	110.70	106.10
	100	---	141.54	123.30	---	104.30	110.10
	200	---	125.53	129.03	---	127.80	107.60
LSD[a]		---	12.16	8.02	---	16.79	12.05
				1985A			
A	0	127.61	125.29	112.87	95.10	112.35	86.11
	50	136.44	118.98	112.69	107.10	109.66	91.80
	100	134.00	116.75	116.84	96.45	114.55	104.95
	200	133.40	119.04	118.84	103.46	120.78	87.86
B	0	142.31	129.22	120.93	102.58	115.57	99.79
	50	139.82	119.82	113.96	98.21	119.35	99.06
	100	133.25	114.17	116.04	114.71	121.51	110.41
	200	134.19	117.72	120.69	121.85	126.59	118.75
LSD[a]		14.74	10.04	10.19	16.58	14.05	25.28
				1985B			
A	0	133.70	125.60	110.13	110.64	127.80	120.03
	50	126.78	130.06	112.22	109.39	137.60	117.59
	100	147.26	136.21	107.08	126.33	141.86	115.59
	200	132.92	126.70	114.84	103.04	131.99	116.03
B	0	141.55	126.07	108.08	129.46	111.82	113.64
	50	142.48	123.55	106.96	100.49	131.73	110.07
	100	141.71	131.69	110.81	107.32	137.67	118.96
	200	153.57	128.27	116.05	98.16	141.03	116.81
LSD[a]		20.61	9.00	8.47	34.41	22.31	20.63

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.14. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage digestible energy (DE, Mcal/kg feed) for three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	3.22	2.85	3.01	3.04	2.94	2.81
	50	3.20	3.01	3.10	3.11	2.99	2.71
	100	3.15	2.93	2.99	3.01	3.01	2.74
	200	3.18	2.90	3.07	3.12	2.75	2.69
B	0	3.19	2.84	3.08	3.03	2.95	2.85
	50	3.22	3.01	3.10	3.04	2.98	2.90
	100	3.17	3.06	3.08	3.03	2.94	2.75
	200	3.12	2.88	3.12	3.01	3.05	2.89
LSD[a]		0.19	0.15	0.09	0.14	0.17	0.12
				1985A			
A	0	3.42	3.30	3.14	3.15	2.70	2.85
	50	3.45	3.33	3.18	3.18	2.98	2.97
	100	3.33	3.33	3.18	3.04	2.92	2.89
	200	3.38	3.35	3.04	3.07	2.97	2.83
B	0	3.46	3.27	3.14	3.07	2.93	2.75
	50	3.35	3.31	3.18	3.07	2.92	2.91
	100	3.37	3.41	3.24	3.07	2.95	2.89
	200	3.40	3.32	3.25	3.15	2.90	2.93
LSD[a]		0.15	0.13	0.17	0.16	0.20	0.19
				1985B			
A	0	3.32	3.23	3.25	3.11	2.68	2.75
	50	3.09	3.24	3.18	3.16	2.66	2.77
	100	3.31	3.17	3.19	3.06	2.68	2.82
	200	3.28	3.17	3.20	2.92	2.72	2.80
B	0	3.23	3.26	3.19	3.13	2.75	2.79
	50	3.27	3.22	3.33	2.96	2.74	2.81
	100	3.22	3.23	3.25	3.09	2.69	2.75
	200	3.16	3.17	3.18	3.09	2.66	2.70
LSD[a]		0.27	0.19	0.14	0.14	0.19	0.16

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.15. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf digestible energy (DE, Mcal/kg feed) for three field trials

Infest Period	PLH Density	Stem DE 14	Stem DE 28	Stem DE Har	Leaf DE 14	Leaf DE 28	Leaf DE Har
				1984			
A	0	---	2.78	2.56	---	3.40	3.41
	50	---	2.97	2.59	---	3.39	3.43
	100	---	3.07	2.52	---	3.41	3.22
	200	---	2.87	2.62	---	3.42	3.45
B	0	---	2.94	2.67	---	3.42	3.30
	50	---	2.98	2.55	---	3.41	3.37
	100	---	2.98	2.55	---	3.41	3.35
	200	---	2.96	2.63	---	3.47	3.35
LSD[a]		---	0.19	0.13	---	0.06	0.14
				1985A			
A	0	3.16	2.63	2.38	3.83	3.36	3.19
	50	3.21	2.61	2.41	3.34	3.33	3.28
	100	3.23	2.55	2.34	3.36	3.38	3.26
	200	3.22	2.67	2.44	3.31	3.37	3.19
B	0	3.17	2.67	2.43	3.44	3.19	3.23
	50	3.09	2.61	2.36	2.63	3.28	3.24
	100	3.16	2.56	2.45	3.36	3.33	3.16
	200	3.13	2.59	2.54	3.48	3.35	3.30
LSD[a]		0.18	0.17	0.18	0.12	0.14	0.11
				1985B			
A	0	3.10	2.54	2.21	3.57	3.08	2.87
	50	3.14	2.64	2.22	3.52	3.16	2.79
	100	3.17	2.75	2.17	3.44	3.18	2.76
	200	3.22	2.64	2.27	3.48	3.23	2.80
B	0	3.18	2.64	2.16	3.50	3.07	2.70
	50	3.27	2.63	2.17	3.48	3.19	2.72
	100	3.09	2.79	2.21	3.48	3.30	2.69
	200	3.21	2.71	2.31	3.49	3.18	2.90
LSD[a]		0.13	0.16	0.17	0.08	0.17	0.25

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table D.16. Comparisons of *in-vitro* digestibility (%), crude protein (%), and cell wall concentration (%) for damaged leaves for three trials at two sample periods. Ames, IA

Trial	Days after Cutting	Percent Digestibility	Percent Protein	Percent Cell Wall
1984	28	83.6	24.6	50.8
	Har	79.7	20.6	46.5
1985A	28	78.8	30.5	44.2
	Har	69.1	27.9	46.4
1985B	28	83.6	25.3	45.2
	Har	79.8	24.2	41.6

APPENDIX E. MEANS AND ANALYSIS FOR NUTRITIONAL YIELD AND PHENOLOGICAL DEVELOPMENT VARIABLES

Table E.1. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage digestible dry matter yield (kg/ha) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
				1984			
A	0	817.3	1108.6	1950.3	3302.7	3314.7	2911.7
	50	577.4	895.8	1652.2	3197.9	2636.5	2344.5
	100	548.9	812.5	1978.6	3032.2	2535.5	2334.6
	200	546.9	761.1	1621.0	2566.9	2397.1	1861.7
B	0	952.2	1358.3	2047.6	1995.8	3045.0	2648.8
	50	789.2	1547.1	1518.1	2339.9	2418.7	2922.3
	100	702.8	1590.9	1736.8	3062.3	2460.3	3125.0
	200	824.6	1182.9	1320.4	2041.5	2555.8	2583.4
LSD[a]		272.7	407.2	508.5	1104.4	899.2	999.9
				1985A			
A	0	614.5	1735.4	2190.1	2603.2	2493.0	4351.7
	50	544.7	1132.4	1509.3	1654.1	1930.0	2759.8
	100	413.7	985.7	1549.5	1984.2	1815.7	1839.1
	200	485.5	948.2	1599.9	2026.5	1870.0	2052.5
B	0	709.5	1444.4	2451.5	2606.5	2799.9	3711.7
	50	568.9	1207.7	1561.1	1787.5	1495.5	2098.2
	100	725.5	1592.5	1892.8	2463.0	2515.1	2701.3
	200	673.1	1543.1	1800.0	2094.8	2106.7	2103.4
LSD[a]		224.2	341.9	614.2	796.4	666.0	999.5
				1985B			
A	0	663.5	1740.9	3634.8	3394.1	2392.7	3340.3
	50	488.7	1248.8	1961.2	1838.7	2471.1	2990.2
	100	502.9	1403.7	2279.1	2232.9	2591.7	2369.3
	200	480.0	1039.5	1841.8	1831.2	3042.9	2657.6
B	0	563.3	1538.3	3187.1	4271.0	3021.6	2882.1
	50	541.0	1218.8	2436.3	1943.7	1978.1	2302.2
	100	607.6	1618.2	2254.4	1960.2	2221.7	2250.2
	200	540.6	1459.5	2554.6	1908.8	2421.3	2535.0
LSD[a]		212.8	631.2	778.9	599.6	109.3	777.1

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table E.2. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf digestible dry matter yield (kg/ha) measured weekly for each of three field trials

		Stem IVDDM			Leaf IVDDM		
Infest Period	PLH Density	14	28	Har	14	28	Har
				1984			
A	0	---	1610.0	1551.5	---	1669.2	1451.7
	50	---	1354.7	1316.3	---	1660.1	1138.6
	100	---	1305.7	1292.6	---	1603.4	1013.4
	200	---	926.3	1064.0	---	1278.1	867.0
B	0	---	939.4	1418.7	---	1142.5	1331.7
	50	---	1184.4	1514.5	---	1246.3	1399.5
	100	---	1488.4	1786.9	---	1711.6	1360.4
	200	---	951.5	1336.8	---	1145.6	1188.4
LSD[a]		---	549.1	673.3	---	633.9	352.6
				1985A			
A	0	995.9	1283.9	1969.6	704.4	1141.2	2203.3
	50	637.4	713.8	1206.7	471.1	751.1	1365.6
	100	544.3	885.5	790.3	425.7	875.5	948.6
	200	526.3	898.5	896.5	394.5	916.1	1030.0
B	0	790.6	1283.0	1961.0	662.6	1161.1	1704.5
	50	599.9	822.7	910.3	571.1	829.8	1020.9
	100	801.7	1104.7	1266.3	710.0	1135.4	1082.4
	200	826.2	887.0	949.9	698.7	953.6	832.8
LSD[a]		184.1	415.4	556.3	146.3	321.9	419.4
				1985B			
A	0	952.1	1786.5	1752.4	823.9	1191.4	1218.9
	50	647.2	893.2	1544.8	627.9	779.0	1048.8
	100	784.9	1217.1	1156.9	658.4	896.7	841.0
	200	574.2	998.2	1396.8	509.2	810.4	915.9
B	0	837.7	2295.5	1457.0	725.7	1547.3	958.1
	50	687.7	1067.9	1096.8	595.1	790.4	836.6
	100	850.3	1023.0	1134.9	795.0	891.7	816.7
	200	824.4	949.7	1362.5	702.0	793.6	964.5
LSD[a]		354.3	331.4	468.5	309.6	261.5	276.5

[a]LSD = least significant difference (P = 0.05).

Table E.3. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage crude protein yield (kg/ha) measured weekly for each of three field trials

Infest Period	PLH Density	Days after cutting 7	14	21	28	35	Har
		1984					
A	0	336.1	361.4	620.4	1014.9	936.7	825.2
	50	239.6	277.2	457.4	827.5	732.3	731.8
	100	215.4	288.4	613.3	815.4	633.8	678.9
	200	207.2	247.2	455.9	604.1	630.4	505.3
B	0	390.2	478.1	778.8	657.4	950.6	832.5
	50	330.7	536.3	528.1	805.3	723.8	906.9
	100	288.5	571.1	584.1	937.2	724.2	969.2
	200	311.8	407.7	426.5	644.4	742.3	765.1
LSD[a]		115.0	184.0	156.7	378.3	250.7	295.7
		1985A					
A	0	303.6	732.4	705.2	938.7	809.4	1376.1
	50	287.8	471.6	468.7	541.7	593.4	883.7
	100	206.4	395.7	543.0	730.3	531.9	601.8
	200	247.0	381.2	522.9	611.7	559.4	667.3
B	0	328.9	632.3	814.9	894.3	819.3	1157.1
	50	274.9	464.2	511.1	631.4	509.4	623.9
	100	356.1	618.2	569.3	808.2	752.5	840.1
	200	324.7	624.0	522.6	652.1	633.9	617.5
LSD[a]		124.2	140.5	199.7	261.6	210.7	340.7
		1985B					
A	0	341.8	768.3	1201.5	1224.1	910.1	1180.3
	50	267.1	582.5	651.6	597.6	906.2	1085.5
	100	237.8	640.2	771.7	759.5	959.9	827.5
	200	235.4	503.6	688.5	682.7	1179.3	861.6
B	0	280.3	679.8	1111.9	1475.7	1224.2	1070.2
	50	260.4	560.4	864.0	708.5	780.6	829.3
	100	300.0	778.2	768.3	666.7	878.5	784.2
	200	261.9	638.9	939.8	662.3	880.9	909.7
LSD[a]		107.1	282.2	312.8	288.6	412.2	325.1

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table E.4. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf crude protein yield (kg/ha) measured weekly for each of three field trials

Infest Period	PLH Density	Stem Protein 14	Stem Protein 28	Stem Protein Har	Leaf Protein 14	Leaf Protein 28	Leaf Protein Har
				1984			
A	0	---	389.7	358.6	---	677.0	468.0
	50	---	306.9	292.4	---	662.4	311.0
	100	---	315.9	298.3	---	627.5	287.0
	200	---	247.3	246.5	---	431.4	188.7
B	0	---	225.9	323.7	---	521.5	502.2
	50	---	302.0	362.7	---	540.9	512.2
	100	---	382.3	431.4	---	769.7	445.3
	200	---	243.8	333.7	---	493.1	368.4
LSD[a]		---	146.7	161.3	---	258.3	99.2
				1985A			
A	0	315.0	307.4	456.3	377.7	438.3	916.5
	50	219.9	173.7	304.4	247.2	287.1	549.3
	100	188.1	216.1	203.2	243.9	384.9	362.9
	200	177.1	219.8	221.5	205.7	313.5	437.2
B	0	261.5	313.5	470.7	333.1	436.9	663.7
	50	207.1	209.9	236.8	282.9	287.1	403.4
	100	284.7	289.1	301.1	357.4	384.9	413.4
	200	283.5	221.6	220.9	348.1	284.8	285.2
LSD[a]		79.0	100.6	125.8	90.8	120.2	156.9
				1985B			
A	0	317.4	459.0	534.3	418.8	546.7	568.5
	50	223.9	218.1	528.1	335.2	368.6	578.8
	100	271.1	298.6	334.9	343.4	400.8	410.2
	200	197.2	279.2	391.2	276.1	357.0	458.8
B	0	277.8	614.3	433.4	376.6	662.5	504.8
	50	238.9	276.5	329.7	298.5	338.9	423.6
	100	272.6	244.0	326.9	412.4	357.1	430.0
	200	274.1	264.7	407.6	369.8	339.1	458.1
LSD[a]		110.5	106.7	161.7	163.7	139.5	109.2

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table E.5. Effect of various infestation periods and densities of potato leafhopper (PLH) on neutral-detergent fiber yield (NDF=cell soluble concentration, kg/ha) for each of three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	494.4	703.5	1378.4	2265.0	2253.3	1948.7
	50	315.4	602.1	1041.5	1846.2	1664.7	1631.0
	100	328.8	518.7	1382.4	1782.7	1497.8	1442.3
	200	339.5	464.0	1020.8	1499.7	1778.0	1167.2
B	0	595.5	953.2	1585.9	1293.2	2101.3	2001.4
	50	526.5	1106.6	1125.9	1625.4	1503.1	1839.5
	100	407.9	1040.1	1194.8	2042.5	1647.8	2081.4
	200	503.4	792.7	902.7	1187.8	1658.5	1579.6
LSD[a]		165.4	286.6	448.8	805.2	577.3	678.4
				1985A			
A	0	482.6	1152.1	1424.6	1594.5	1570.4	3073.2
	50	407.5	759.5	842.5	1014.6	1242.5	1625.9
	100	344.1	635.4	965.4	1158.6	848.4	1288.8
	200	369.9	659.9	963.5	1014.7	1144.1	1352.2
B	0	564.7	1052.7	1468.8	1876.0	1663.2	2547.2
	50	425.4	729.4	846.9	1055.1	1036.9	1276.5
	100	628.9	1038.0	1009.5	1428.4	1393.1	1688.5
	200	522.9	989.4	1014.5	1173.9	1320.7	1296.9
LSD[a]		183.2	242.2	390.6	607.4	558.9	700.2
				1985B			
A	0	485.5	1007.1	1900.1	1978.8	1334.2	1458.0
	50	383.0	816.3	1104.5	1107.2	1488.0	1690.2
	100	342.3	854.6	1353.3	1275.1	1470.9	1340.7
	200	346.1	635.5	1113.7	1126.1	1810.7	1763.0
B	0	413.6	937.8	1836.9	2544.1	1749.4	1412.7
	50	368.4	743.1	1554.6	1243.5	1234.2	1335.9
	100	427.7	963.0	1341.6	1193.6	1297.5	1250.6
	200	360.6	981.9	1694.5	1250.3	1362.2	1488.4
LSD[a]		171.2	395.5	489.5	400.4	616.3	597.8

[a]LSD = least significant difference (_P_ = 0.05).

Table E.6. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf neutral-detergent fiber yield (NDF=cell soluble concentration, kg/ha) for three field trials

		Stem NDF			Leaf NDF		
Infest Period	PLH Density	14	28	Har	14	28	Har
				1984			
A	0	---	1074.1	939.9	---	1308.3	987.7
	50	---	855.6	746.4	---	1222.8	754.5
	100	---	801.0	761.9	---	1112.0	700.1
	200	---	610.8	621.7	---	675.2	580.0
B	0	---	584.0	909.0	---	856.5	988.0
	50	---	808.2	874.6	---	945.4	1091.2
	100	---	819.9	1103.3	---	1342.4	1039.9
	200	---	653.8	751.5	---	780.1	913.0
LSD[a]		---	383.5	414.6	---	484.2	242.8
				1985A			
A	0	679.6	749.0	1365.0	572.5	860.1	1931.5
	50	401.6	497.1	852.9	369.3	577.5	1178.6
	100	352.0	623.3	460.0	349.6	655.8	742.6
	200	340.1	635.0	558.1	314.7	658.1	906.1
B	0	459.8	736.9	1073.9	518.9	874.7	1391.8
	50	350.9	568.0	599.1	463.1	606.3	836.6
	100	520.5	810.3	841.3	529.4	806.2	846.4
	200	533.8	623.0	614.9	490.0	658.6	609.5
LSD[a]		119.0	278.3	318.5	111.1	244.0	360.5
				1985B			
A	0	585.0	1003.6	1106.0	606.1	802.3	882.6
	50	433.3	497.8	911.2	462.4	454.7	779.0
	100	425.3	625.9	781.4	456.9	535.3	623.8
	200	377.9	591.8	787.2	392.3	534.8	697.1
B	0	513.6	1403.5	916.7	495.7	1196.6	732.9
	50	388.5	686.3	719.6	461.1	525.7	665.0
	100	482.4	613.2	644.5	614.2	553.6	582.1
	200	410.0	572.8	781.8	553.7	453.6	698.1
LSD[a]		271.6	235.7	321.8	247.8	208.5	271.8

[a]LSD = least significant difference (*P* = 0.05).

Table E.7. Effect of various infestation periods and densities of potato leafhopper (PLH) on forage digestible energy yield (DE, Mcal/ha) measured weekly for each of three field trials

		Days after cutting					
Infest Period	PLH Density	7	14	21	28	35	Har
				1984			
A	0	3469	4701	8273	14011	14058	12344
	50	2451	3800	7011	13569	11183	9935
	100	2329	3446	8393	12863	10756	9894
	200	2321	3228	6878	10892	10161	7889
B	0	4041	5760	8688	8467	12915	11230
	50	3350	6564	6441	9927	10259	12391
	100	2983	6751	7369	12991	10435	13244
	200	3499	5017	5603	8660	10843	10954
LSD[a]		1158	1728	2158	4687	3817	4239
				1985A			
A	0	2610	7367	9294	11047	10564	18450
	50	2313	4808	6405	7020	8187	11705
	100	1757	4185	6576	8417	7700	7797
	200	2061	4026	6788	8598	7931	8702
B	0	3013	6132	1040	11058	11874	15731
	50	2416	5128	6625	7584	6342	8898
	100	3080	6763	8034	10449	10667	11451
	200	2858	6551	7641	8890	8934	8920
LSD[a]		952	1452	2607	3379	2824	4239
				1985B			
A	0	2817	7389	15429	14402	10138	14157
	50	2073	5300	8323	7803	10470	12675
	100	2135	5957	9673	9473	10981	10044
	200	2037	4411	7817	7765	12899	11266
B	0	2391	6530	13527	18123	12807	12217
	50	2297	5172	10344	8244	8383	9760
	100	2579	6868	9569	8317	9415	9537
	200	2294	6194	10842	8098	10260	10743
LSD[a]		904	2679	3308	2544	4633	3296

[a]LSD = least significant difference ($\underline{P}$ = 0.05).

Table E.8. Effect of various infestation periods and densities of potato leafhopper (PLH) on stem and leaf digestible energy yield (DE, Mcal/ha) measured weekly for each of three field trials

Infest Period	PLH Density	Stem DMI 14	Stem DMI 28	Stem DMI Har	Leaf Protein 14	Leaf Protein 28	Leaf Protein Har
				1984			
A	0	---	6824	6571	---	7088	6164
	50	---	5746	5576	---	7049	4835
	100	---	5539	5474	---	6809	4301
	200	---	3927	4507	---	5428	3682
B	0	---	3984	6010	---	4852	5653
	50	---	5024	6415	---	5292	5942
	100	---	6313	7567	---	7268	5776
	200	---	4036	5663	---	4865	5046
LSD[a]		---	2328	2851	---	2692	1497
				1985A			
A	0	4226	5439	8335	2991	4845	9351
	50	2546	3024	5107	2000	3189	5797
	100	2310	3750	3344	1807	3718	4027
	200	2234	3807	3795	1675	3890	4372
B	0	3355	5436	8301	2814	4928	7235
	50	2546	3485	3852	2425	3522	4333
	100	3402	4677	5360	3015	4820	4593
	200	3506	3757	4023	2967	4049	3536
LSD[a]		781	1759	2357	622	1367	1781
				1985B			
A	0	4039	7566	7410	3500	5055	5168
	50	2746	3784	6532	2667	3306	4446
	100	3331	5158	4891	2796	3806	3565
	200	2437	4229	5908	2163	3440	3883
B	0	3555	9726	6159	3082	6565	4060
	50	2919	4524	4637	2527	3355	3546
	100	3608	4337	4799	3377	3786	3461
	200	3499	4025	5764	2981	3368	4090
LSD[a]		1503	1403	1983	1315	1110	1173

[a]LSD = least significant difference ($\underline{P}$ = 0.05).